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Patricia Ruis Hawn

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Lauren Julius Harris
Major professor

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HAND ASYMMETRIES IN GRASP DURATION AND REACHING IN TWO- AND FIVE-MONTH-OLD HUMAN INFANTS

By

Patricia Ruis Hawn

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ABSTRACT

HAND ASYMMETRIES IN GRASP DURATION AND REACHING IN TWO- AND FIVE-MONTH-OLD HUMAN INFANTS

By

Patricia Ruis Hawn

Studies of infant handedness relying on reaching for objects have found hand differences at 7 months. When duration of grasp of objects is measured, a right-hand advantage has been found at 2.7 months. These, plus studies of cerebral and postural asymmetries in infants suggest a genetic basis for functional lateral asymmetry of the brain.

This study assessed manual asymmetries in two- and five-month-olds with right-handed parents. Measures included unimanual and bimanual grasp duration and ipsilateral and contralateral reaching.

The unimanual task showed a right-hand advantage for both ages, the bimanual task for older infants only. There was a right-hand advantage in speed of reaching for older infants, but no hand differences in frequency. Familial handedness predicted individual differences in performance. Four infants of left-handed parents showed a left-hand advantage.

The results support genetic theories of handedness and

and emphasize consideration of motor skills when constructing handedness measures for infants.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

The purpose of the current study is to determine the presence and extent of manual asymmetries in early infancy as measured by hand differences in grasp duration and reaching. Selected developmental studies of manual asymmetry and other asymmetries in infancy are summarized, and their relationship to various theories of handedness is discussed. Measurement issues are condsidered, particularly with reference to the developmental sequence of motor skills in infancy. The relationship of manual skill and manual preference is discussed, with emphasis on the nature of the assessment tasks employed for individuals at a given age.

Developmental Studies of Manual Asymmetry

Over the last 100 years, there have been many studies of the development of handedness in individuals. Some of these studies have been directed to providing support for a general theory. Some have consisted of observation of the hand behavior of a single child in controlled or, more often, in uncontrolled settings. Some pioneer attempts to investigate the early phases of hand preference are those of Darwin (1877), Baldwin (1890, 1894), and Woolley (1910).

Charles Darwin (1877) noted that his own child, at age 77 days, held the feeding bottle exclusively in the right hand. About one week later, the left hand began to be used for this action. Darwin reported having found this pattern, the left hand lagging somewhat behind the right, in several other actions which he does not describe. When the child eventually became left-handed, Darwin concluded that some genetic mechanism must have been at work, since the child's grandfather, mother, and brother were also left-handed.

Baldwin (1890, 1894) studied handedness by eliciting reaching for objects presented to his infant daughter. Testing was conducted over a six month period beginning when the infant was four months old. The experiments included reaching for a number of different objects at varying distances and in unsymmetrical directions. Baldwin was aware of the prevalent theories of handedness of his day, especially those that attributed handedness to the supposed preferential carrying of the infant on the mother's right side, and to differences in weight of the two lateral halves of the body. Baldwin therefore controlled certain elements of his daughter's environment to rule out the effects of carrying and weight differences. She was never carried about in her caretaker's arms, was frequently turned over while sleeping, and was not allowed to balance herself on her feet until a later period.

Baldwin (1890, 1894) found no continued preference for either hand in reaching as long as no, in his words, "violent muscular exertion" was required. By presenting objects just out of the infant's reach, more effortful reaching was elicited, and a right-hand preference was noted by the seventh month. Based on these findings, and the controlled conditions of his daughter's environment, Baldwin concluded that some more fundamental physiological asymmetry must be involved in handedness.

Helen Woolley (1910) used tasks similar to Baldwin's reaching tasks to test her daughter's hand preference during infancy. No consistent hand preference was observed when distances to be reached were small, but a right-hand preference appeared at seven months when reaching required some amount of effort. Woolley also noted that the right-hand position possessed an attraction for the child, independent of the hand used in reaching. That is, the right-hand position was chosen more often than the right hand was used. No explanation was offered for this position preference. Woolley concluded that right-hand preference cannot be explained as a result of training but that it must be a part of normal physiological development.

Both Baldwin and Woolley mention the possible association of speech and right-hand usage because of the proximity of the cortical control areas for these abilities. Since Baldwin's daughter was not making any articulate sounds at the time that the right-hand preference appeared, Baldwin concluded that handedness can develop independent of speech. Woolley found that onset of right-hand preference coincided with onset of babbling, but that early establishment of a decided right-handedness at ten months was not accompanied by an early acquisition of speech. Baldwin, Woolley, and other early investigators also found evidence of early periods of left-hand preference later over-shadowed by consistent right-hand usage, a finding confirmed by Gesell and Ames with a larger sample.

Lippman (1927) studied hand preferences of 178 infants in reaching for one, two, or three objects presented in succession. No clear, consistent hand preference in reaching for a single object was observed until eight months of age. By age one year, the right hand was used in approximatley 75% of the reaches. Similarly, Voelckel (1913; cited in Giesecke, 1936) observed the emergence of right-hand preference in reaching at seven months of age.

Under the influence of John B. Watson (1924, 1925), a behaviorist account of handedness development came to the fore. Watson conducted a series of tests of handedness using infants. He found no consistent significant hand differences in anatomical structures such as width of left and right wrist, palm, and length of forearm, suspension time with each hand, total amount of work done with each hand, and reaching for objects with each hand. He concluded, ". . . there is no fixed differentiation of response in either hand until social usage begins to establish handedness" (Watson, 1924, p. 101). He labeled left-handers as those capable of withstanding social pressure, and seemed to advocate shifting left-handers to the use of the right hand, with the caution that it should be accomplished before the onset of speech. Watson was not implying a neurological connection between handedness and speech. Rather, he stated that the word and the manual act are simultaneously conditioned, interference in one being associated with interference in the other.

Giesecke (1936) observed two male and two female infants for periods of up to six months. She found significant differences in the amount of spontaneous activity of the two hands (as did Stubbs & Irwin, 1933) that were related to preferential use of the hands in reaching. She also found evidence for periodic shifts in hand dominance, specifically at seven months and again at ten months, and suggested an inverse relationship between degree of hand dominance and the extent of fluctuation in dominance.

Gesell and Ames (1947) conducted what is probably the most thorough longitudinal study on the development of hand preference and its early predictors. Their subjects were normal children, studied from age eight weeks to ten years. Descriptive analysis consisted of the observer's commentary on the infants' behaviors. Quantitative measures included total time the infants at each age, in supine and sitting positions, used the right hand, left hand, and both hands when contacting an object, and the percentage of time in the supine position during which the infants maintained a left tonic neck posture (TNR), a right TNR, or a bilateral posture. The TNR measure was included on the basis of previous findings of a definite right preference (e.g., Gesell & Halverson, 1942). The terminology used by Gesell and others may be confusing. It is not clear that term "TNR" is used here the way a pediatric neurologist would use it in reference to the obligatory reflex that is part of the standard neurological examination. A more precise description of the behavior examined by Gesell is an asymmetric head-posture preference.

Results showed shifts in handedness, for which a developmental rationale was formulated. Even in eventual right-handers, there were several shifts in hand usage with age. Contact and manipulation were first observed with the non-dominant hand. At age 18 months, there was marked bilaterality, which by age 24 months was replaced by use of the dominant hand. Bilaterality recurred from 30 to 42 months, but use of the dominant hand in most situations returned around 4 years and continued. In some cases, at about 7 years, there was a period of bilaterality or use of the non-dominant hand.

A relation was noted between hand preference and head posture preference. Analysis of film recording revealed 65 distinct posture patterns, 64 of which were toward the right. The asymmetric posture, clearly present in the first eight weeks after birth, less evident at 12 weeks and more or less symmetric at 20 weeks, was predictive of later handedness in 75% of the subjects.

Using portions of Gesell's procedure, Seth (1973) longitudinally studied the development of eye-hand coordination and handedness in nine infants from 20 to 52 weeks of age. At the earliest stages, the left hand predominanted in terms of the frequency of coordinated use with vision, the frequency of being the dominant hand in a situation, and the frequency of being successful in contacting an object. The shift to the predominance of the right hand at eight to ten months anticipated by approximately eight weeks the attainment of a comparable level of achievement by the left hand.

These observations are consistent with the earlier view that manual dominance begins to differentiate at about the same time that language begins. That is, the early predominance of left-hand use is replaced by right-hand preference at approximately the same age that speech begins its rapid development. One possible explanation of this shift is that, early in development, the infant's behavior is under predominantly control of the right cerebral hemisphere (Harris, 1975; Meyer, 1911). Most of the abilities representative of the sensorimotor period are perceptual abilities known or likely to be subserved primarily by the right hemisphere in adults. They include auditory localization (Wertheimer, 1961), size and shape constancy (Bower, 1966), and depth perception (Gibson & Walk, 1960). If the right hemisphere of the brain is truly dominant in infancy, early left-hand preference is a reasonable expectation. As the left cerebral hemisphere changes over time, speech and right-hand preference emerge together. Further evidence of this association comes from findings that both hand preference (Gesell, 1940) and language (Harris, 1977) develop earlier in females than in males, and that delay in speech development is often accompanied by a delay in handedness development (Gesell, 1940, p. 194). These findings suggested examination of sex differences in the current study.

All the studies mentioned previously used frequency of use of each hand in reaching as the measure of hand preference. As Caplan and Kinsbourne (1976) noted, certain basic motor skills of infants could not be considered by the use of this method. For example, infants between six and twelve months of age tend not to cross the midline of personal space when they reach for objects. Therefore, if the object was at all to the left or right of the infant's midline, that positioning would determine the hand used in reaching. This criticism, however, is of less importance when one considers that it implies that the infant is affected by a deviation from midline that goes unnoticed by the experimenter. Furthermore, there is evidence that older children and adults tend not to cross body midline when imitating hand movements (Harris, unpublished manuscript; Schofield, 1976). Caplan and Kinsbourne also suggest that the younger infants in the six to twelve month age range have not outgrown the tendency to reach with both hands together. Both of these factors would reduce the likelihood of revealing a hand preference in reaching.

Caplan and Kinsbourne therefore proposed measuring duration by each hand. The rationale for this new technique is based on the relationship of asymmetric head posture to the grasp reflex. It has been noted that the vast majority of infants' head postures while supine are toward the right (see the discussion of the work of Turkewitz and associates below). Caplan and Kinsbourne consider this response to be a basic selective orienting response, involving the inspection of a stimulus before the decision to approach or withdraw. Since an obvious asymmetry is present in this inspection phase, it is reasonable to search for a similar asymmetry in the approach phase, i.e., the grasp, that follows.

Using this new technique, Caplan and Kinsbourne (1976) found that infants of mean age 2.7 months held a rattle longer, on average, with the right hand than with the left hand. These results indicate that asymmetry may be present at an earlier age than previous studies indicated. They also suggest that the consistent finding of a period of left-hand predominance before the development of right-hand preference may be an artifact of using a complex behavior such as reaching, to determine hand preference. If the required behavior is so complex as to exceed the capacity of the left hemisphere, the right hemisphere may assume control, resulting in a left-hand advantage. With a less complex response such as grasp, however, the capacity of the left hemisphere would not be exceeded and it would maintain control, thereby producing a right-hand superiority in duration of grasp.

Other Asymmetries in Infants

If hand preference, as it develops in infancy, is related to the development of the cerebral hemispheres, other asymmetries should be evident. The asymmetries that have been most frequently studied are cerebral asymmetries and postural asymmetries. Cerebral asymmetry for the processing of dichotic sounds has been found in infants from 22 to 140 days of age using an habituation/recovery of sucking technique (Entus, 1975). Recovery scores favored the right ear when verbal stimuli were used and the left ear when non-verbal stimuli were used. Similarly, following habituation of cardiac orienting, nine of twelve 3-month-old infants showed greater recovery of orienting when a new musical stimulus was presented to the left ear and a new speech stimulus to the right ear (Glanville, Best, & Levenson, 1977). Auditory evoked responses over the left and right temporal lobes of infants ages one week to ten months have been measured (Molfese, Freeman, & Palermo, 1975). With speech sounds, larger responses were found over the left side, and with music or noise bursts, larger responses were found over the right side. All of these studies indicate that infants show a right-ear (left hemisphere) advantage for the processing of language sounds, and a left-ear (right hemisphere) advantage for the processing of music sounds and noise, a pattern like that found in most adults (Kimura, 1967).

To identify other asymmetries in infants, the relationship between handedness and cortical somato-sensory evoked response (SER) has been studied in infants and children between ages 3 1/2 months and 4 years of age (Cernacek & Podivinsky, 1971). Hand preference was measured by observing the subject reach for an object at midline and sixty degrees to the left and to the right of midline. Using this test, approximately 80% of subjects under the age of one year were classed as ambidextrous. For these infants, no differences in SER amplitude were noted following differential stimulation of the left and right sides. In older children with a consistent hand preference, the amplitude of the left hemisphere response to contralateral stimulation was greater than that of the right hemisphere. All of these findings of cerebral asymmetries in infancy suggest that the related manual asymmetry may also be an early development.

Studies of postural asymmetries have been carried out by Turkewitz and co-workers. Turkewitz, Gordon, and Birch (1965a) reported that, in 75 three-day-old infants, the response typically elicited by lateralized tactile stimulation of the perioral (mouth) region was a head-turn in the direction of the stimulation. Ipsilateral responses were more readily elicited by stimulation of the right side than of the left side. Contralateral responses were rare, but when they occurred, they were usually in response to stimulation of the left side. That is, the infants' more frequent head-turns were to the right side.

This right-turn preference was confirmed (Turkewitz, Gordon & Birch, 1965b). Eighteen of twenty infants observed showed a marked lateral preference in head position. Seventeen of these infants maintained the head to the right of the body midline exclusively, and one did so predominantly. No infant showed a clear-cut preference for the head-left posture. Further observation of several hundred infants disclosed that a great majority preferred the head-right posture while in a supine position. This preference could not be accounted for on the basis of either the arrangement of the nursery, or the nurses' placements of infants in their basinets.

In an attempt to explain this posture preference, researchers focused on infants who did <u>not</u> show the common trend. Do these infants differ from the majority in any other ways? Turkewitz and Birch (1971) examined the relation between the infant's condition at birth and his later posture preference. Although infants whose condition at birth is poor appear normal within several days, there is evidence that they show a relatively high frequency of abnormalities in motor, language, and intellectual functions during later infancy and childhood (Corah et al., 1965; Graham et al., 1962). The results indicated that infants in poor condition at birth (Apgar below 6) made head turns as frequently as normal infants did (Apgar at or above 6), but differed in the direction of the response. Infants with intermediate or high Apgar scores made significantly more responses to stimulation at the right than at the left, while infants in the low Apgar group exhibited no such lateral difference in responsiveness, and in fact showed a non-significant trend toward greater responsiveness to stimulation of the left side. The percentage of subjects who were more responsive to stimulation on the left than right was significantly greater in the low than in the high Apgar group. Those infants in the low Apgar group who did show the typical pattern (i.e., greater responsiveness on the right) were less differentiated than normal infants.

This asymmetry of head posture and responsiveness to stimulation can be seen in infants as young as two days of age (Turkewitz & Creighton, 1975). The infant not only spends most of his time with his head to the right, but also is more responsive to auditory, somesthetic, and visual stimuli applied to the right side. Further study has shown that these differences in responsivenss are artifacts of the initial head-turn preference (Turkewitz, 1977). Forced maintenance of the infants' heads in a midline position resulted in elimination of the characteristic lateral differences in responsiveness.

The basis for the infant's initial head-right bias has not been identified. Some attentional mechanism may be operating as suggested by Caplan and Kinsbourne (1976). If so, the origin of the attention bias remains to be explained. If manual, cerebral, and postural asymmetries all have their origins in an attentional asymmetry, is that attentional asymmetry learned or innate, or are manual and postural asymmetries the result of cerebral asymmetries that are unrelated to attention? Are the asymmetries learned through experience or are they part of the genetic information that governs development?

Theories of Handedness

The question why most individuals prefer one hand to the other has long baffled and excited scholars and scientists in many disciplines. Proposed explanations run the gamut from reliance on purely cultural or learning influences to complete genetic determinism. Most theories fall under one of four classifications. First, there are theories that attribute handedness (generally lefthandedness) to negative or pathological influences on emotional or biological function. The second category includes theories supporting a learning or conditioning process as the determinant of individuals' hand preference. The third and probably largest category includes explanations dealing with anatomical and physiological asymmetries of various body systems as determinants of or related to manual asymmetries. Among the theories here are the structural theories of visceral distribution, blood supply and brain structures, as well as functional theories of eye domiance and cerebral dominance. Finally, a fourth category of theories has attributed handedness to some hereditary mechanism, either genetic or, more recently, oocytic.

Negative or pathological influences. Theories that postulate pathological influences are concerned mainly with explanations of left-handedness. One variation assumes that right-handedness is the normal well-adjusted type of reaction, while left-handedness represents a rebellion against the right-handed world. Blau (1946), for instance, maintained that left-handedness represents a psychological and social deviation. He contended that handedness *per se* is learned by a process of social conditioning, and that left-handedness is a result of faulty conditioning because of an inherent physical or mental deficiency, faulty education, or emotional negativism. He drew support from evidence of higher incidence of left-handedness in individuals with abnormal mental development e.g., retardates, epileptics, psychiatric patients.

A less extreme position was taken by Burt (1937), who considered that some sinistrality may be explained by negativism, while some may result from a strong physiological bias. It seems unwarranted to induce the characteristics of normal sinistrals from abnormals, as Blau did. It is more reasonable to consider the possibility that left-handedness in such abnormal groups is quite different from normal sinistrality (Brain, 1945; Gordon, 1920).

A fundamental difference was established between natural and pathological left-handedness by Gordon (1920). Of eight pairs of uniovular twins of opposite hand preference, Gordon showed that the left-handed child is frequently mentally retarded. Gordon assumed that a lesion of the left cerebral hemisphere was responsible both for the mental retardation and for the weakness of the right hand, which induced the child to pathological left-handedness. In natural left-handedness, the left-handed twin is equal to the right-handed one, in intelligence and manual skill. The pathological left-hander, then, appears to have a two-fold disadvantage--from his brain lesion, and from the required use of his less-skilled hand (Subirana, 1969).

Although he makes no distinction between genetic and pathological left-handedness, Bakan (1971, 1977; Bakan, Dibb, & Reed, 1973) has suggested a relationship between left-handedness and neurological insult. He found a higher proportion of sinistral writers than dextrals in high risk birth order categories (first-born, and fourth-or later-born). Assuming birth order to be a reliable indicator of stressful prenatal and birth conditions associated with neurological damage, a relationship between neurological insult and left-handedness was hypothesized. However, the study appears faulty on several methodological grounds. First, the sole measure of handedness used was that of writing hand. The use of a single measure does not allow for differentiation of various types of left-handedness. Second, there was no direct assessment of prenatal or birth complications. Rather, they were assumed to have occurred, based on the individuals' birth order positions. Failure to replicate these findings adds further weight to these criticims, and suggests that the results may be a result of sampling error (Hubbard, 1971; Schwartz, 1977). Sampling error has also been cited (Bakan, 1977) as an explanation for the replication failures. Subject populations from different socioeconomic levels are likely to show different rates of pregnancy and birth complications among late births than would samples drawn from lower socioeconomic levels. The difference in the infant mortality rate across socioeconomic levels also may create differences in the nature of the samples.

From the discussion above, two distinctions about lefthandedness can be noted. First, contemporary theorists identify the pathology as physical rather than emotional. A second distinction, that between pathological and normal left-handedness, has been recognized by past as well as contemporary theorists. This hypothesis of a relationship between pathological left-handedness and brain insult, and an extension of the concept of pathological handedness to include pathological <u>right</u>-handedness, have been examined further by Satz (1972, 1973).

Satz (1972) has devised a mathematical model to explain the relationship of pathological left- and right-handedness to the consistent reports of a two-fold increase in left-handedness in epileptic and retarded populations compared to normal controls. The model assumes an eight per cent incidence of sinistrality in normal populations (based on Hécaen & deAjuriaguerra, 1964), and random occurence of lesions in either cerebral hemisphere. With a hypothetical population, Satz determined that the incidence of manual switch after contralateral brain injury has a probability of occurence $p = .21$. Based on this figure, the number of pathological (i.e., shifted) sinistrals far exceeds that of pathological dextrals, the latter being restricted by the low frequency of natural left-handedness in the population. Satz also postulates that four of five retarded or epileptic subjects who are manifest sinistrals have a primary lesion in the left hemisphere, and that the incidence of manifest left-handedness will be raised primarily in brain-injured populations with perinatal or early post-natal injury, assuming more switching of handedness while the nervous system is more flexible. These predictions were tested and confirmed against an actual clinical sample (Penfield & Roberts, 1959).

The phenomenon of pathological handedness is accepted by clinicians as one limited explanation of handedness patterns. The three remaining categories of handedness theories have broader applications to the ontogeny of manual asymmetry in normal populations without brain injuries.

Learning or conditioning. There have been many "learning" theories, but only a few are worth mentioning. The so-called "heliocentrism" theory (Wile, 1934) and "warfare shield" theory (usually attributed to Pye-Smith or Carlyle; see Clark, 1957; Harris, in press; Parsons, 1924) have little applicability to the question of individual hand preference.

The more influential theories have proposed that handedness is a product of social conditioning or habit formation (Hildreth, 1948, 1949; Hurlock, 1977; Jackson, 1905; Watson, 1924, 1925). Jackson argued, for example, that handedness is entirely a matter of habit and, moreover, that children should be taught to use either hand interchangeably. Hildreth stated that handedness is a learned characteristic, citing in support evidence of increased asymmetrical hand preference for highly trained behaviors (e.g., writing, eating). Watson argued that social usage establishes handedness, but realized that this idea fails to account for left- and mixed-handers. Left-handers and mixed-handers were cases of individuals who had stubbornly resisted social conditioning. Most recently, Hurlock has stated that the empirical evidence concerning handedness supports a learning theory and excludes any genetic theories. Obviously, even some contemporary authors remain unaware of recent work.

According to a theory frequently attributed to Plato (e.g., Wile, 1934, p. 128), but erroneously so (Harris, in press), the general weakness of the left side stems from the infant's being carried on the mother's right arm. This position forces the infant's left side to remain essentially immobile and the right side to be free for exercise, thus conditioning the development of a right-hand preference. Although this theory was doubted from the onset (see Harris, in press), more recent experimental work has shown that mothers prefer to carry their infants on their left side, either to keep their more dextrous right hand free or unconsciously to keep the infants closer to the soothing maternal heartbeat

(Salk, 1973). A study of 546 adult-child pairs has confirmed the left-side tendency for mothers, but found it to be less pronounced than Salk reported (Rheingold & Keene, 1965). In contrast, fathers more often held their children on their right side. There was no relationship between handedness of parent and the side on which they held their child. Rheingold and Keene also reported that the children's hands were free in 67% of their observations, which indicates that child-carrying practices probably do not affect handedness in the manner that the theory predicts. Further evidence of a left-side preference in child-holding can be seen in early Christian art (Burt, 1937) and in Impressionist and Post-Impressionist paintings (Finger, 1975).

More recent variants of a learning explanation consider learning or practice to be influential, but not the sole determinant of manual asymmetry. Hildreth's (1948) evidence for increased asymmetry with increased practice could suggest that training serves to strengthen an already-present asymmetry. It is also possible that the complexity of the skill is the critical variable. That is, less complex activities can be controlled equally well by either hemisphere of the brain, while more complex skills may be controlled only by the hemisphere specialized for that specific skill. If training interacts with cerebral asymmetry in the development of hand preference, it is essential that these asymmetries, both structural and functional, and their implications for hand preference, be examined.

Asymmetries of cerebral structure. Beginning about 1860, the known functional specialization of the left cerebral hemisphere stimulated many attempts to identify supposed underlying anatomical asymmetries (Geschwind, 1974; Harris, in press; von Bonin, 1962). A variety of brain measurements were made, including weight, specific gravity, and skull length. The reported differences, however, were slight, inconsistent, and seemingly inconsequential.

With respect to actual brain structures, recent work using sophisticated techniques of dissection and measurement has confirmed previous findings (Pfeifer, 1936; cited in Geschwind, 1974) of asymmetry in the occipital horns and the planum temporale. In individuals with asymmetrical occipital horns, the left is longer in 57% and the right in 13% (McRae, Branch, & Milner, 1968). In right-handed neurological patients, the left-longer pattern is five times more likely than the right-longer pattern, while in left-handed patients there is no difference in the difference in the incidence of the two patterns.

In a sample of 100 adult brains, the planum temporale an extension of Wernicke's area in the temporal speech cortex, was on average one-third longer on the left side in 65% of the cases (Geschwind & Levitsky, 1968). Neonatal brains also have been examined for the presence of a similar asymmetry prior to establishment of hand preference (Witelson & Pallie, 1973). For both linear and area measurements, significantly larger left planums were found in neonates age two to twenty-one days at time of death. For groups of males and females matched for age, the left-right difference reached significance for females in the youngest group only. This finding should be interpreted with caution, however, because it is based on a small sample. Also, it is not clear that a sex difference is actually present. More recently, it has been determined that the asymmetry of the planum temporale becomes measurable by the twenty-ninth week of gestation (Wada, Clarke, & Hamm, 1975).

Along with these gross anatomical differences in the cerebral hemispheres, finer asymmetries have been noted (Galaburda, LeMay, Kemper, & Geschwind, 1978). The gross asymmetries are reflected in regions of differing cellular architecture of differing sizes on the two sides. Certain radiological measurement techniques which can be used on large numbers of living subjects without risk (e.g., computerized axial tomography) have confirmed the planum and occipital horn assymetries and have demonstrated asymmetry in the occipital and frontal lobes.

<u>Asymmetries of cerebral function</u>. Most speculation about the functional correlates of handedness now centers on cerebral specialization, particularly language lateralization. Based largely on extensive examinations of clinical populations, in particular patients who have become aphasic following unilateral brain damage, it has been estimated that approximately 98% of all right-handers have their language functions predominantly subserved by the left hemisphere (Penfield & Roberts, 1959; Wada & Rasmussen, 1960). Similarly, it is estimated that 50-70% of non-right-handers also have their language functions localized primarily within the left

hemisphere (Goodglass & Quadfasel, 1954; Hécaen & Sanguet, 1971; Wada & Rasmussen, 1960). The wide range of this estimate is consistent with the general finding that left-handers as a group are more heterogeneous in cerebral organization than right handers. These findings imply that for nearly all right handers, major cortical control for language lies in the left hemisphere, whereas in a significant proportion of left-handers, the major language control is in the right hemisphere.

Several researchers have suggested that linguistic abilities may be bilaterally represented in left-handers, that is, the two hemispheres share more nearly equally in linguistic functioning (Beaumont, 1974; Chesher, 1936; Hécaen & de Ajuriaguerra, 1964; Kimura, 1967; Levy, 1974; Subirana, 1969; Zurif & Bryden, 1969). There are several sources of evidence to support the hypothesis of bilateral language representation in left-handers. It has been observed that left-handers are more likely than right-handers to become aphasic following damage to either hemisphere (Lhermitte & Gautier, 1969). A second source is provided by use of Wada's (1949) technique, involving injection of sodium amytal into the carotid artery to induce temporary aphasia. Among 117 left-handers, 15% displayed aphasic symptoms following both left- and right-side injections, whereas only one of 95 right-handers showed this effect (Milner, Branch, & Rasmussen, 1964). A third source is the observation that left-handed aphasics suffer less severe symptoms, are more likely to recover their language skills, and do recover more quickly than right-handed aphasics (Goodglass & Quadfasel, 1954; Luria, 1970; Zangwill, 1960).

Other indications of bilateral representation of language in left-handers come from studies of neurologically intact individuals using dichotic listening and tachistoscopic visual presentations. Left-handers show a smaller right ear advantage and smaller visual field differences than right-handers, thus suggesting a less nearly complete language lateralization in the former (Kimura, 1961, 1967; Beaumont, 1974; Levy, 1974).

It may be fairer to say that there are at least three groups of left-handers. First, there are those who are left hemisphere dominant for language, constituting about 60% of the total population of left-handers. Second are those who are right hemisphere dominant for language, about 20% of the total. Finally, there is the sub-group with bilateral language representation, again about 20% of the total. Even finer distinctions may be made. It is possible for example, that those left-handers with left hemisphere dominance are still less lateralized than right handers.

A model developed by Semmes (1968) suggests that the form of cerebral organization may influence motor functions such as handedness. Focal representation for both contralateral and ipsilateral sensorimotor functions is to be found in the left hemisphere, while that in the right hemisphere is diffuse. Such organization would favor the integration of functionally similar units within the left hemisphere, a process vital for fine sensorimotor control used in manual operations and speech. Beaumont (1974) recently formulated a general model emphasizing the differences in cerebral organization between right-handers and left-handers. Primarily, the overall organization of the left-hander is more diffuse, resulting in less specialization and greater homogeneity of function. Cerebral diffuseness is seen as a more general characteristic of the left-hander's brain, not a characteristic tied specifically to language. Once again, the implication is that the cerebral organization of left-handed persons differs from that of right-handed persons.

The picture of differential cerebral organization associated with different hand preferences has been further complicated by the introduction of the variable of familial handedness history. The relation of familial sinistrality to the direction and degree of language lateralization is unclear. Some investigators (e.g., Annett, 1973) have associated familial left-handedness with decreased left hemisphere dependence for language. Others (e.g., Hécaen & Sauguet, 1971) have suggested that bilateral representation of language is present only in familial left-handers. Still others (e.g., Newcombe & Ratcliff, 1973) have found that individuals with <u>non</u>-familial sinistrality are more likely to show unusual patterns of cerebral organization.

These findings of cerebral asymmetries, and those discussed previously of asymmetries in infants, suggest the presence of a biological substrate for handedness. Numerous genetic models have been proposed, but there is no single model of choice yet. Familial sinistrality does not necessarily reflect a genetic mechanism, but may be the result of a familial tendency toward birth stress. The currently debated genetic theories, however, do attempt to deal with the questions raised above about the relationship between cerebral dominance and handedness.

Genetic theories. There have been persistent attempts to attribute the variation in handedness to a genetic code for the direction of laterality. Both Ramaley (1913) and Jordan (1914) stated that handedness followed the Mendelian laws, with left-handedness being recessive. The strict recessive model, however, predicts that left-handed couples should always produce left-handed offspring. Chamberlain (1928), after studying the handedness of a population of over 12,000, criticized the model, saying, " . . . there can be no doubt that the trait (i.e., left handedness) is inherited, but surely not as a Mendelian recessive" (p. 559). He was led to this conclusion by findings that showed that left-handed parents did not always produce left-handed offspring. To explain such departures from strict Mendelian law, some authors have added the concept of variable penetrance. Trankell (1955) argued that only some of the individuals homozygous for the left-handed gene will actually be left-handed. Rife (1950) proposed that partial penetrance is expressed only in heterozygotes, not in homozygotes.

Rife's theory is elaborated by Annett (1964), who suggests that a single, two-allele gene is responsible for handedness and cerebral dominance for language. According to her model, individuals homozygous for the normally dominant allele are always right-handed and have speech represented in the left cerebral hemisphere; those homozygous for the normally recessive allele show the reverse pattern; while heterozygotes are inconsistent. Most heterozygotes will develop the normally dominant pattern (approximately 75%). One difficulty with Annett's model, pointed out by Levy & Nagylaki (1972), is that it cannot account for the finding that a majority of left-handed individuals are left-hemisphere dominant for speech. Annett did suggest that heterozygotes, but not recessive homozygotes, are more likely to shift handedness or speech laterality following left hemisphere injury, but one must also propose that cerebral damage is more likely to be followed by a shift in handedness than in speech laterality (Satz, 1972).

Levy and Nagylaki's (1972) two-gene, two-allele model eliminates the proposed variable penetrance. Instead, one gene is assumed to determine direction of hemispheric lateralization for language functions, the other determines whether the preferred hand will be contralateral or ipsilateral to the language hemisphere. The dominant alleles are those for left-hemisphere language and contralateral (i.e., right) hand preference. The two genes interact to determine handedness. Whether the control pathways are ipsilateral or contralateral depends on one gene, while the actual left-right choice depends on the other.

Several criticisms have been leveled against these genetic theories. First, it has been argued that directional information is probably coded in the cytoplasm of the egg rather than in the genes (Morgan, 1977). Morgan finds no good evidence to suggest that the direction of an asymmetry is inherited genetically. Rather, right-handedness is the result of positional information encoded in the oocyte, favoring development of the left side. Levy (1977) has replied that the ultimate informational source must be the gene, since the cytoplasmic structure is itself a consequence of information in the gene's DNA.

A second problem with genetic theories, noted by Corballis & Beale (1976), among others, is that handedness does not seem to be a truly dichotomous variable, a characteristic difficult to reconcile with a single, two-allele gene model. Finally, Collins (1970, 1977), after reanalyzing data on handedness among sibling pairs and twins, has concluded that any correlations of handedness are very low (phi = .075). Although the use of twins raises some difficulties (e.g., increased pathology, questions of mirror imaging effects, intrauterine crowding, birth stress), the coefficient is equally small for paired siblings. Collins argues that genes are indifferent to the direction of asymmetry, but may influence its degree. Nagylaki and Levy (1973), however, are critical of the use of twins as a method of testing genetic models. They also draw attention to errors in and misinterpretations of the data.

In light of these criticisms, Annett (1972, 1973, 1975) has revised her earlier model. She now proposes two components underlying the distribution of human handedness, one a bell-shaped component, reflecting random or accidental influences, the other a right-shift component, which Annett assumes to be genetic. The latter accounts for the fact that most people are right-handed, the former explains the lack of consistency between twins and siblings. Left handedness is attributed either to a "weak dose" of, or the absence of, the right-shift factor. Most non-familial left-handers would be classified as pathological (Annett, 1973, 1974). Handedness in the children of two left-handed parents depends on the normal distribution of random, accidental influences. That is, there are genetic influences toward right-, but not toward left-handedness (Annett, 1973, 1974).

Measurement and Incidence of Manual Preference

Testing any of these theories requires an assessment of handedness that will yield estimates of the incidence and degree of right, left, and mixed handedness in the population. The assessment of manual preference can be accomplished in several ways. The most commonly used procedure is the questionnaire or inventory (Annett, 1967; 1970; Benton, Meyers & Polder, 1962; Bryden, 1977; Oldfield, 1971; Raczkowski, Kalat, & Nebes, 1974). Personal and familial handedness history is a critical part of these inventories, especially when used for clinical diagnosis (Subirana, 1969). Verbal report, or self-classification, is not sufficiently sensitive, the major problem being that left-handers so classified are a very heterogeneous group (Benton et al., 1962). Motor performance tests of both gross and fine skills are essential tools, though most often used with children whose language skills may preclude completing a completing a questionnaire (Benton et al., 1962; Ojemann, 1930a, 1930b; Provins & Cunliffe, 1972; Updegraff, 1932).

The findings based on these tools indicate that handedness is a continuum divisible at several levels of discrimination. Most investigators find the incidence of left-handedness to be between four and ten percent (Annett, 1967; Hécaen & de Ajuriaguerra, 1964; Johnson & Davis, 1937; Johnson & Duke, 1940). Annett (1967), for example, found right-, mixed, and left-handedness to be in binomial proportions of 66%, 30%, and 4% in the population. Another general finding is that left-handedness is less frequent in females than in males (Bryden, 1977; Oldfield, 1971).

Measurement represents an important methodological consideration because variations in the sensitivity of the tests used to determine hand preference will be associated with handedness groups of differing compositions. For example, when writing hand is the only skill used to classify a group of sujbects as to hand preference, the group classified as left-handed will be more heterogeneous than if questionnaires and dexterity tests had been used. Use of more sensitive tests will reveal a clearer picture of the differential abilities associated with handedness. The issue of the validity of various ways of measuring handedness also has implications for developmental studies of manual preference, inasmuch as the infant studies previously discussed have yielded different ages of onset of hand preference based on the use of different measures.

Motor Skill Development

A research area closely related to the development of manual asymmetry, but often ignored in studies of manual asymmetry, is that of the devleopmental course of various manual skills, especially grasping, reaching, and object manipulation. An experimenter must be aware of the manual capabilities of infant subjects before searching for the presence of hand preference in such skills. During the 1920's and 1930's, much research in child psychology was concerned with charting the course of motor development. A substantial contribution was made by Gesell (1925-1950), who proposed maturation as the fundamental explanatory concept. According to his principle of "individuating maturation," the growth impulse is basically endogenous rather than exogenous. Environmental factors were seen to support and in some circumstances to specify, but they did not engender the basic ontogenetic sequences. Gesell also postulated the principles of developmental direction and functional asymmetry, both of which can be applied to manual skill development. Development proceeds along the principle axes of the body (i.e., cephalo-caudal and proximo-distal), and as it proceeds, unilateral preferences replace bilateral functions.

The purest form of maturation hypothesis of motor development is no longer deemed adequate (Connolly, 1970). More complex models of motor skill learning have been proposed (Adams, 1971; Bruner, 1970; Elliott & Connolly, 1974; Hogan & Hogan, 1975).

Development of prehension from the first crude groping to the use of refined grasp is a major accomplishment of infancy

(Kopp, 1975). Of the recent research dealing solely with grasping in infancy, the observations of Twitchell (1965; 1970) are the most detailed. He has distinguished three kinds of automatic grasping responses in infants during the first four months. The first of these, the traction response occurring in neonates, is a flexor synergy of the upper limb elicited by stretching the shoulder adductors and flexors. The second, the grasp reflex, consisting of a flexion-adduction of the fingers and elicited by a contact stimulus to the palm, emerges between one and three months of age. The third, the instinctive grasp reaction, is a complex exploratory and prehensile response, also elicited by a contact stimulus to the hand and developing between the fourth and tenth months.

Development of reaching and object manipulation has been studied by many researchers. Bower and co-workers (1972; 1975; Bower, Broughton, & Moore, 1970a, 1970b) have studied reaching within the broader framework of object perception and object concept development, attempting to delineate the stimulus conditions necessary to elicit reaching. Bruner's approach (1968; Bruner & Koslowski, 1972) conceptualizes skilled activity, such as reaching, as a program specifying a serial order of constituent subroutines required to reach a terminal goal, and focuses on the early coordination of skilled activity with visual information. Halverson's (1931, 1932, 1937) detailed studies describing reaching responses and the prehensile grasp were founded on Gesell's maturational theory. McGraw (1941, 1943) suggested that increased skill in reaching and prehension was the result of neurological maturation, with mature reaching being characterized by maximum efficiency in use of both the visual and neuro-muscular components. Piaget (1936; Piaget & Inhelder, 1965) suggested that the coordination of vision and prehension in reaching is an example of the process of reciprocal assimilation during the sensorimotor period.

Relationship of Manual Skill and Preference

Most studies with adults and with children do find a relationship between manual skill and manual preference to the extent that hand preference is more pronounced on skills that are highly learned. The skills assessed include pressure reproduction, speed of tapping and turning a crank (Provins, 1956), handwriting and typewriting (Provins & Glencross, 1968), speed of peg moving (Annett, 1968; 1970), and aiming, steadiness, fine dexterity, and reaction time (Barnsley & Rabinovitch, 1970). With adults, this finding of increased asymmetry on highly learned skills has been attributed to a process of automatization of a skill that is highly practiced and overlearned with the preferred hand.

With children, the relationship between skill and preference appears to be more task-specific. On a peg-moving task, Annett (1968, 1970) compared speed of movement with each hand in 3 1/2- to 15-year-old children. While 15-year-olds were faster overall, they showed no more difference in favor of the preferred hand than did 3 1/2-year-olds. Annett suggests that this finding supports genetic over an environmental theory of handedness, with practice being influential only for those individuals with potential for developing skilled usage of either hand (mixed preference).

In contrast, other studies of manual dominance in nursery school children ages two to five years have shown that those acts most subject to training, e.g., eating with a spoon, throwing a ball, using a crayon, were much more frequently carried out by the right hand than those tasks less subject to training, such as eating with fingers, shaking a rattle, drinking from a glass (Hildreth, 1948; Ingram, 1975). The difference between these two sets of findings may lie in the nature of the task. Peg-moving may be a skill that is not highly practiced or over-learned in older children and adults; thus one would not expect to find increases with age in favor of the preferred hand. However, in adults, the preferred hand has been shown to do better on similar skills (Barnsley & Rabinovitch, 1970).

It is likely that preferential hand use does increase with training and/or practice. This possibility, indeed, was suggested by early writers (cf. Baldwin, 1890). Consequently, it may be the direction of manual asymmetry that is genetically coded, while the degree of the asymmetry for a particular skill is established by practice and experience. Even in such rudimentary skills as grasping and reaching, infants may be expected to show asymmetrical hand usage which increases with development. This increasing lateralization may reflect the effects of practice on the hand predisposed for more skillful capabilities, or an increase in the asymmetrical organization of the cerebral hemispheres reflected in preferential hand use.

Contributions of the Current Study

The current study was carried out with several aims in mind. First, it was hoped that clearer evidence would appear bearing on the question of the developmental sequence of manual asymmetry. While it is generally concluded that manual asymmetry does not appear until seven to twelve months, Caplan and Kinsbourne's (1976) findings indicate that the use of a more sensitive measurement may reveal differences much earlier.

Second, the finding of sex differences in early manual asymmetry may bear on the role of practice as opposed to cerebral asymmetry in hand preference. If no sex differences are present, this could suggest that practice may be a key to increased manual asymmetry. There is no reason to expect different amounts of practice based on sex. It is also possible that an absence of sex differences indicates that anatomical asymmetries in the infants' cerebral hemispheres (e.g., Witelson & Pallie, 1973) are not sufficient to account for hand preference. Studies of cerebral specialization and postural asymmetry in infancy have revealed no sex differences. However, if a sex difference favoring increased manual asymmetry in females over same-age males is found, the over-all greater neural maturation of females (i.e., increased cerebral asymmetry) may be the underlying causal determinant. In either case, one would expect increasing manual asymmetry with increasing age.

Finally, a variation on the reaching technique as a measure of hand preference is introduced as an answer to Caplan and Kinsbourne's criticism of earlier studies of reaching. This revised technique calls for placing one object in an infant's hand and then presenting an identical object on the same side of body midline. Any preferential hand use in actual reaching or in time required to reach therefore would not be the result of spurious factors such as object placement.

METHOD

Subjects

The subjects were 20 two-month-old and 20 five-month-old infants (mean ages 62 days and 153 days respectively), ten males and ten females in each age group. All of these infants had two right-handed parents, based on self-reports and confirmed by a handedness questionnaire (Raczkowski et al., 1974). Names of potential subjects were drawn from Ingham County birth records and from birth announcements in local newspapers. Participation was solicited by mailing letters explaining the research to the parents of these infants. Approximately two weeks later, parents were contacted by telephone to determine their willingness to participate. Appointments for home visits were made at this time.

In the course of contacting and testing subjects, four additional infants with one or both left-handed parents were obtained. These infants were tested, and will be discussed separately.

Materials

The materials used in testing the infants were three pairs of small barbells made of balsa, consisting of a dowel 1 cm in diamter and 5.1 cm in length, with a 2.5 cm cube attached to each end. Each pair was painted a different color to aid in sustaining the infant's interest. The choice of the color used in each trial was random with the constraint that on trials on which two barbells were presented, the two were the same color.

The entire test session was video-taped using a standard portable Sony video-tape unit with a zoom lens. Both sound and picture were recorded for later scoring by two independent raters and the experimenter.

A questionnaire was given to the parents for completion (see Appendix A). Part 1 consisted of ten items that assessed parents' personal hand preference. These items were selected for high reliability and validity on the basis of task performance, from work by Raczkowski et al. (1974). Part 1 also assessed handedness history of the infant (the parents' parents and siblings, and the infants' siblings). Part 2 contained questions about pregnancy and delivery of the infant. Part 3 was an adapted form of the Carey Questionnaire for assessing infant temperament (Carey, 1973). Parents were also given a description, with illustrations, of the asymmetrical head posture preference (see Appendex B) and were asked to observe and record the direction of at least fifteen instances of this posture in their infants (if possible). The questionnaire and description/observation record were left with the parents for about two weeks, and then were picked up by the experimenter.

Research Design

All infants were tested in their homes with one or both parents present. Based on the parents' knowledge of their infant's daily schedule, testing took place when the infant was usually most active and alert. The infant's state was monitored throughout testing, and testing was conducted only when the infants were in a quiet awake or active awake state (scale constructed by Brackbill & Fitzgerald, 1969; see Appendix C). Three infants were rescheduled for later testing on the basis of state (two crying, one drowsy). For the remaining infants, the test session did not appear to be overly arousing.

All infants were randomly assigned to posture and order conditions with the constraint that equal numbers of males and females from each age group were assigned to each condition. The posture condition specified whether the infant was tested while seated or supine. Supine infants were tested lying on the floor, with the parent at their heads and the experimenter at their feet. Seated infants were tested on their parent's lap, firmly supported, with the experimenter directly in front of them. The order condition specified whether testing was begun with the right or left hand. The tests were administered in the following order for all subjects--reaching, bimanual grasp duration, and unimanual grasp duration. This order was chosen, based on the performance of several pilot subjects, as representing the continuum from most to least attention and physical exertion required. Ceilings were assessed by the experimenter throughout testing with a stopwatch.

1. Reaching. Reaching is defined as the movement of the arm toward an object. The hand may be fisted or open and there may or may not be actual contact with the object (White et al., 1964). To assess hand use in reaching, a barbell was placed in one of the

infant's hands and an identical barbell was presented at approximately thirty degrees from body midline on the same side as the occupied hand, and approximately 20 cm. from the infant's face so as to be well within reach. Four trials were presented, alternating hands, half the trials beginning with placement of the object in the left hand, and half beginning with the right hand. Each trial was scored for the hand used for reaching and for crossing, and the latency from presentation of the second object to full arm extension. If 150 seconds passed after the second object was presented and the infant did not look or move its arm toward the object, both objects were removed and the trial was repeated.

2. Bimanual grasp. The procedures for this test and the unimanual test are identical to those of Caplan and Kinsbourne (1976). Bimanual grasp duration is defined as the number of seconds that an infant can maintain his hold on two objects, one in each hand. Four trials were presented, each beginning when the objects were placed in the infant's hands and ending when the objects were dropped. Each trial was scored for the time that each hand kept hold of the object. After the infant dropped one object, 60 seconds were allowed to pass before the other object was removed. If both objects were held for 150 seconds, the objects were removed and the trial was repeated.

3. Unimanual grasp. Unimanual grasp duration was defined as the number of seconds that an infant held an object in one hand alone. Four trials were presented, each beginning when a barbell was placed in one of the infant's hands and ending when it was

dropped. For half of the subjects, testing began with the right hand, and for half with the left hand. On the remaining trials, the hands were alternated. If the infant held the object for 150 seconds, it was removed and the trial was repeated.

Procedure

Upon arriving at the infant's home, the experimenter assembled the video equipment and placed it directly facing the infant to discourage any asymmetric posture or attention whcih could affect manual asymmetry. The infant was positioned on the basis of preassigned posture, and the testing was begun. The tasks were presented in the predetermined order to each infant. After testing, the questionnaire and posture description/observation record were explained to the parents and any questions were answered. The entire test session, excluding the assembling of the video equipment, lasted from 20 to 30 minutes. Two to three weeks after testing, the experimenter returned to each home to pick up the questionnaires and observation records, and to answer any further questions.

RESULTS

Subject Characteristics

Data from the parents' questionnaires and the TNR observation record were analyzed to obtain information about some characteristics of the subjects. Forty of the infants had two right-handed parents and no history of left-handedness in either set of grandparents or in siblings. Two of the infants had left-handed fathers and two had both left-handed parents. These four infants also had some history of left-handedness in the paternal grandparents and in older siblings. The forty infants with no history of familial sinistrality were the main subjects of study. The remaining four infants' performances will be discussed following discussion of the main results.

The mean birthweight of the infants was 7.2 pounds and the mean gestation period was 39 weeks. There were no premature or low-birth-weight infants in the sample. There was one post-mature male who weighed 10 pounds at birth and had a gestation period of almost 44 weeks. None of the infants experienced any complications at birth, and none were delivered by Caesarian section. Twenty-seven infants were delivered without the aid of obstetrical medications, and five were delivered by the LeBoyer technique. Twenty-seven infants were first-born, eleven were second births, and six were third or later.

Analysis of the temperament questions showed all infants to be well within the norms given by Carey (1973). Based on the parents' observations and records, information on the infants' head posture preferences was obtained. All two-month-old infants showed a strong preference for the head-right posture. Of all asymmetrical postures recorded, 87 percent were toward the right, with no infant showing a head-left preference. In the five-month-old group, all but three infants showed no preference in posture. Those who showed a preference did show a head-right preference, but not so frequently or so strongly as the two-month-old infants. The parents who observed no preference were asked to recall whether their infants showed a preference at a younger age. This retrospective information indicated that 14 of the remaining 17 infants preferred a head-right posture.

Based on all the information above, it appears that the sample of subjects was in no way unusual. The suffered no harmful prenatal or birth experiences, and have had no serious illnesses or injuries. Their temperament characteristics fall within the normal range. Their overall development as indexed by TNR preference appears to be progressing normally.

Descriptive Analysis

Before proceeding with the quantitative data analysis, it may be helpful to give a brief descriptive analysis of what the infants are actually doing during the test session. During the trials measuring unimanual and bimanual grasp, the two-month-old infants appeared quite passive, almost as if they were unaware that anything was happening. Their grasp of the barbells seemed quite loose. When tested in a supine position, most of the infants held the barbells in their hands with their arms bent at the elbow, so that their hands were close to their ears. When tested in a seated position, the infants typically held their arms straight down at their sides or toward their laps. In both positions, there was little movement of the arms. In the reaching trials, the two-month-olds once again were quite passive. The arm positions were much the same as noted previously. The free, unoccupied hand usually showed some motion, although the motion was of the fingers only. A major problem was getting the infant to attend to the second barbell. Once his attention was focused, the finger movements began, often accompanied by a sucking motion of the mouth. The movements of the arms toward the second barbell were slow, with frequent stops and starts. Very few bilateral approaches were observed. If the reach was made by the arm and hand holding the first object, that first object was not dropped to allow for grasping the second object. Actual contact with the second object was infrequent.

In contrast, the five-month-olds appeared much more active during the grasping trials. Their grasp was much stronger, making it difficult to remove the barbell when the trial ceilings were reached. There was a great deal of arm movement in this age group. Often the infants held the barbells in front of their faces and appeared to be looking at the objects. This activity was often accompanied by excited vocalization. The same general behaviors were observed during the reaching trials. The infants were very active, both motorically and vocally. None of the attentional characteristics noted in the two-month-olds were observed in the five-month-olds. Following the presentation of the second barbell, the first movements observed were of the unoccupied hand. These movements were followed by a more rapid, almost ballistic, swiping reach. No bilateral approaches were observed. If the reach was made by the arm and hand holding the first object, that object was generally dropped at some point before or during the reach itself. Actual contact with the second object occurred in a majority of the reaches, although grasping of the second object occurred infrequently.

Scoring of Video Tapes and Quantitative Analyses

All video tapes were scored by two independent raters unaware of the purposes of the study, and by the experimenter. Duration of unimanual and bimanual grasp was scored as the number of seconds the infant held the barbell. Reaching trials were scored for the hand used for reaching (left, right, or neither) and for the latency to reaching (elapsed time from object presentation to full arm extension across body midline). Inter-rater reliabilities, i.e., correlations between scores assigned by each rater, were $r = .99$ for grasp duration and $r = .97$ for latency.

Preliminary tests showed no significant differences between scores obtained from infants in supine and seated positions

($t < 1.00$, n.s.), so these groups were combined in all analyses. A 2 x 2 x 2 x 2 x 2 analysis of variance was performed on the unimanual grasp duration scores and the latency scores, with sex, age, and order (left hand first or right hand first) as between-subjects factors, and hand and trial as repeated measures within subjects. A 2 x 2 x 2 x 2 x 2 analysis of variance was performed on the bimanual grasp duration scores, with sex, age, and order as between-subjects factors, and hand and trial as repeated measures within subjects. Correlational analyses were performed for age and sex with total number of reaches and crosses (reaches across body midline). Within each age and sex, correlated t-tests were performed on the total number of reaches and crosses for each hand.

Unimanual grasp duration. The main effects for age and hand were significant. As expected, grasp duration was significantly longer for the five-month-olds than for the two month olds ($F(1,32) = 450.3$, $p < .001$), and significantly longer for the right hand than for the left ($F(1,32) = 670.7$, $p < .001$). These main effects were qualified by a significant age x hand interaction, illustrated in Figure 1. Simple effects tests showed the hand difference to be significant for both the two-month-olds ($F(1,32) = 12.69$, $p < .01$) and the five-month olds ($F(1,32) = 21.73$, $p < .01$). Although the slopes of the lines appear to indicate a greater asymmetry in the five-month-old groups, comparison of laterality indices for the two groups provides a clear picture. The laterality index is a means of comparing the degree of

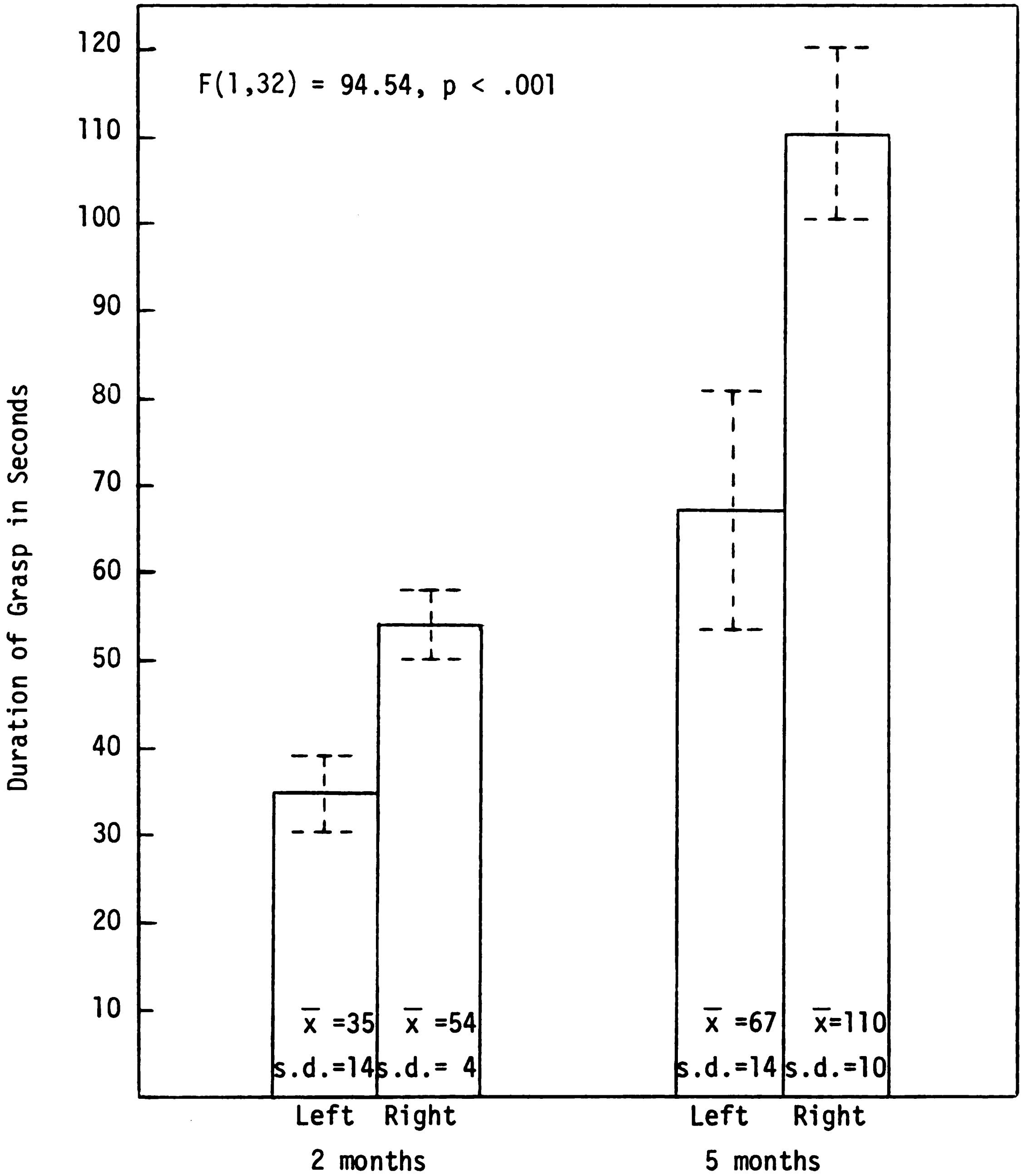


Figure 1. Duration of unimanual grasp in seconds for each hand, within each age group, over all conditions.

asymmetry between the hands while controlling for overall grasp duration. It is calculated by the following formula (Marshall et al., 1975):

$$LI = \frac{\text{R mean} - \text{L mean}}{\text{R mean} + \text{L mean}}$$

Negative scores indicate an asymmetry in favor of the left hand and positive scores in favor of the right hand. All individual laterality indices for both age groups were positive. The laterality indices for the two age groups were not significantly different. That is, the five-month-old infants are not more asymmetrical than the two-month-olds on the unimanual task.

Bimanual grasp duration. The main effects for age and hand were significant. Grasp duration using both hands at once was significantly longer for the five-month-olds than for the two-month-olds ($F(1,32) = 181.4$, $p < .001$). As was previously the case, these main effects were qualified by a significant age x hand interaction, illustrated in Figure 2. Analysis of simple effects showed the hand difference to be significant for the five-month-olds ($F(1,32) = 10.65$, $p < .05$), but not for the two-month-olds ($F(1,32) = 2.08$, n.s.). This finding was supported by comparison of lateral indices calculated for the bimanual task. Once again, all individual indices were positive. On this task, the five-month-olds were significantly more asymmetrical in their hand use than the two-month-olds. It is possible that the bimanual task interferes with or masks the hand asymmetry in a way that the unimanual task

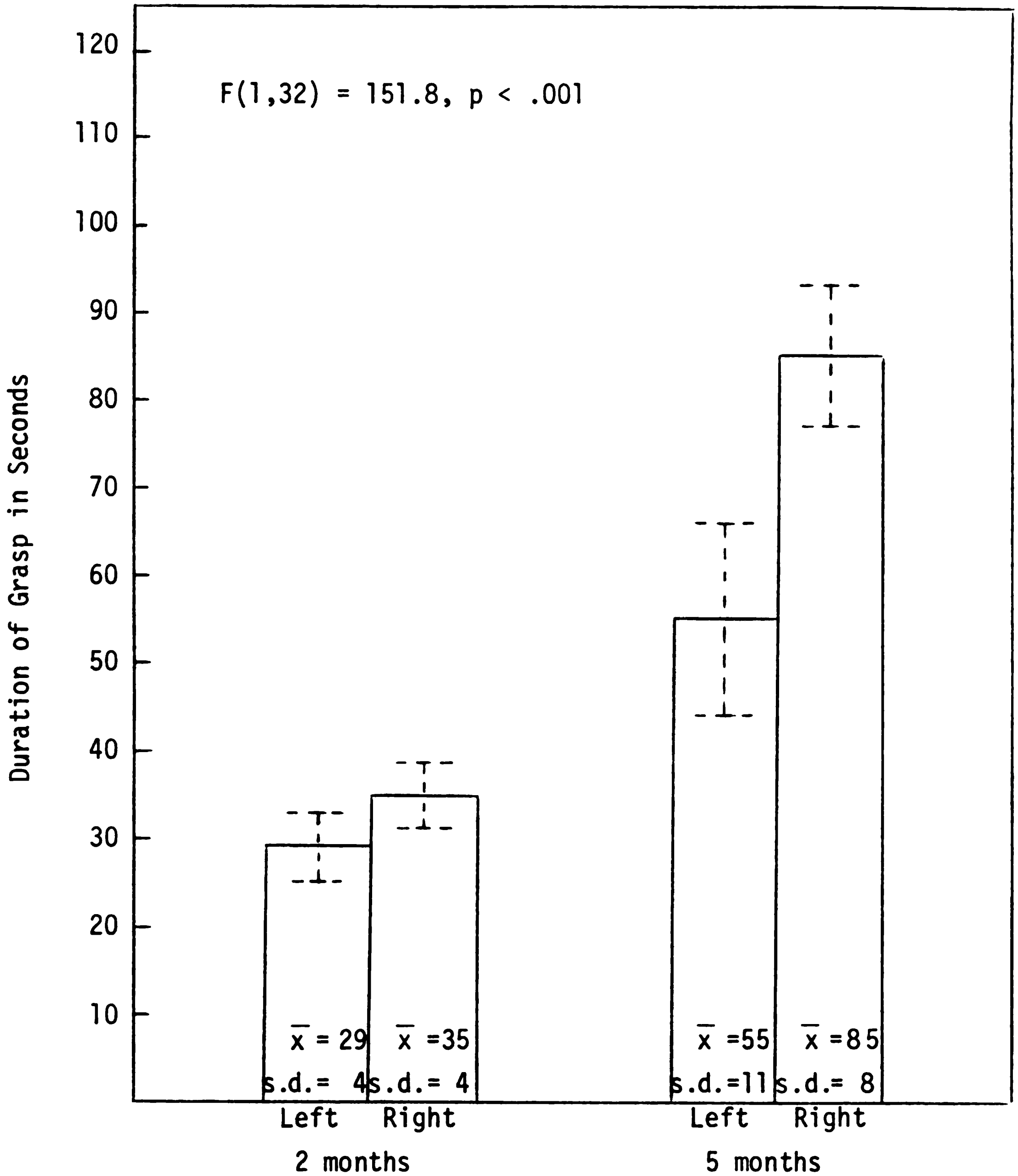


Figure 2. Duration of bimanual grasp in seconds for each hand, within each age group, over all conditions.

does not. The increased difficulty of dealing with two objects simultaneously may cause the younger infants to fall back on the more reflex-like form of grasp that shows no asymmetry (Twitchell, 1970).

Reaching. Correlations of total reaches and crosses with age and sex indicated that the total number of reaches and crosses increased with age ($r = .79$ and $.88$ respectively, $p < .001$). No sex differences in reaches and crosses were found ($r = .06$ and $.11$, respectively, n.s.). As with previous reports of reaching among infants of the ages used here, no hand differences were found in reaching or crossing. Although five-month-old infants reached for objects more frequently and crossed their body midline in reaching more frequently than two-month-old infants did, they did not show a hand preference in reaching. However, analysis of the latency data indicates that the simple frequency count is midleading. Main effects for age and hand were found in reaching on the same side of body midline ($F(1,32) = 10.47$ and 5.31, p's $< .05$ respectively) and across body midline ($F(1,32) = 23.15$ and 13.47, p's $< .005$, respectively). That is, older infants reached more quickly overall than younger infants. Reaches with the right hand occurred more rapidly after objects presentation than did reaches with the left hand.

These main effects were qualified by several significant interactions. There were significant age x hand interactions both for reaching and for crossing body midline, illustrated in Figures 3 and 4. Simple effects tests as well as comparisons of laterality

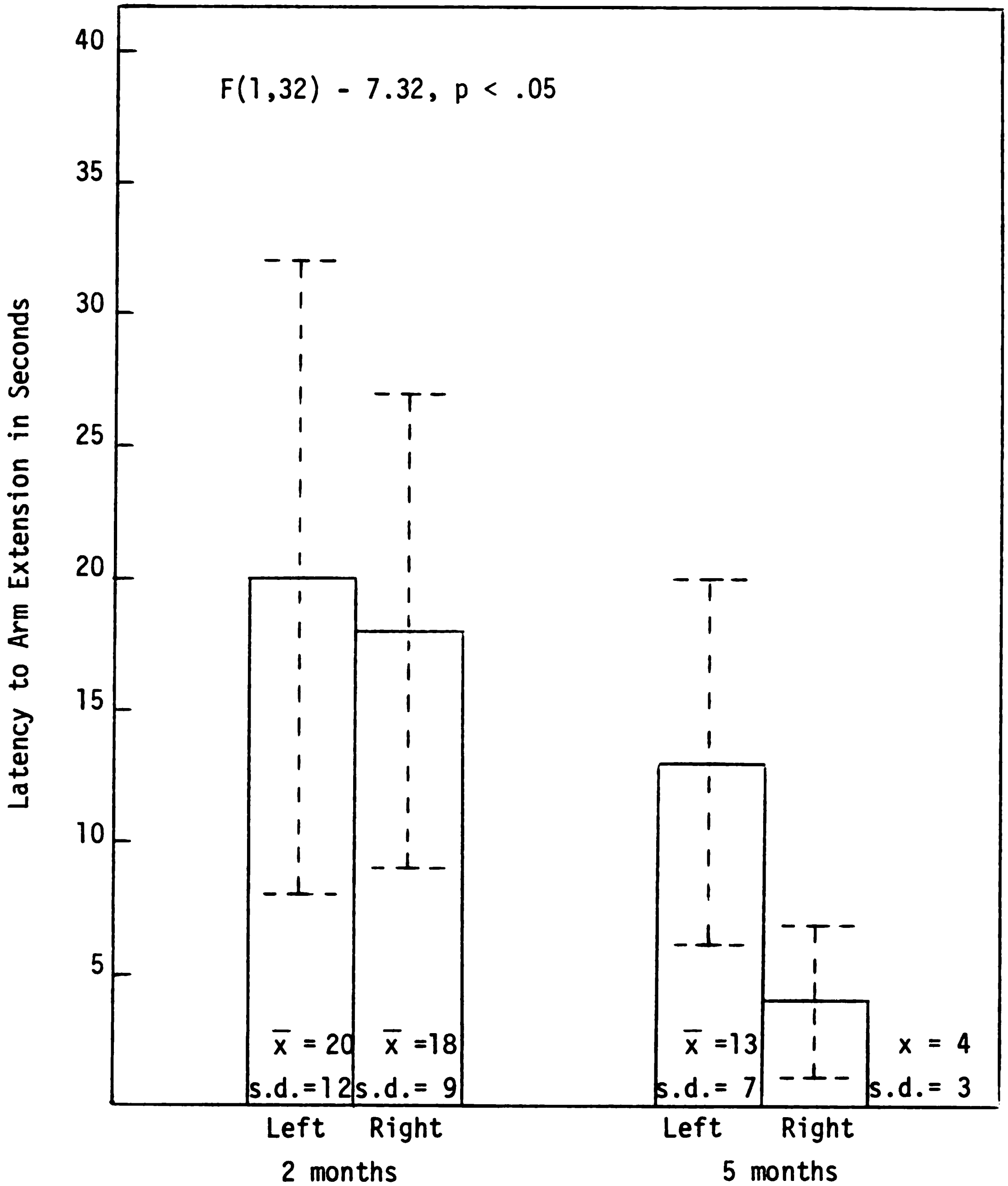


Figure 3. Latency to ipsilateral reaching in seconds for each hand, within each age groups, over all conditions.

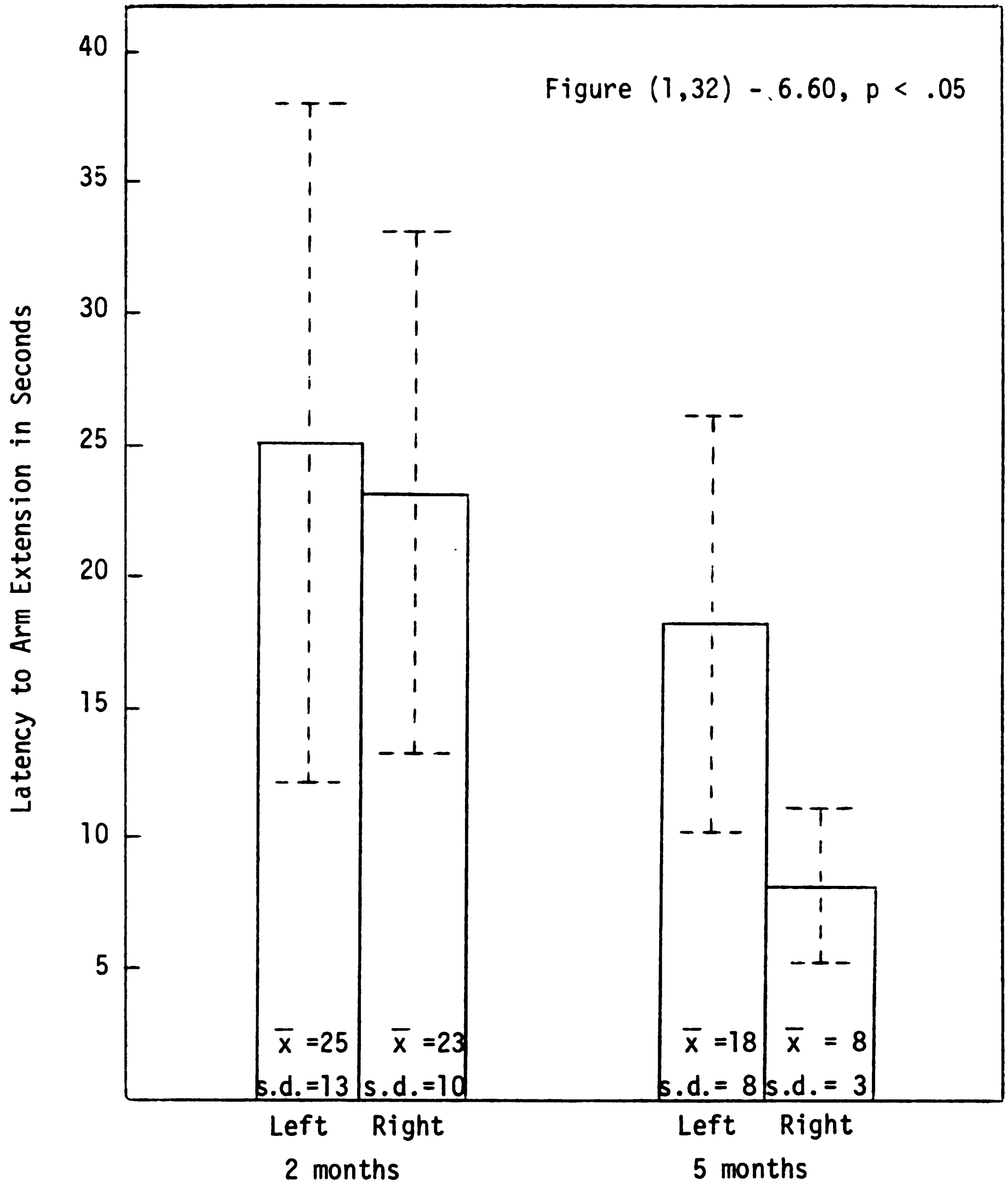


Figure 4. Latency to contralateral reaching in seconds for each hand, within each age group over all conditions.

indices indicated that the asymmetry was significant for the five-month-olds ($F(1,32) = 7.37$ and 13.76, p's $< .05$ respectively) but not for the two-month-olds ($F(1,32) = 2.08$ and 2.92, n.s.). In the case of reaching across body midline, this interaction is further modified by a significant Age x Hand x Trial interaction ($F(1,32) = 6.31$, $p < .05$) shown in Figure 5. Across trials, the right hand shows more overall improvement than the left hand ($F(1,32) = 14.52$, $p < .05$ for right; $F(1,32) = 2.67$, n.s., for left). There was improvement in both age groups ($F(1,32) = 12.83$, $p < .01$ for 5 mo.; $F(1,32) = 17.4$, $p < .005$ for 2 month). The largest improvement was among the two-month-olds for the right hand.

Infants of Left-Handed Parents

These findings with infants of two right-handed parents can be compared to those of the four infants with one or both left-handed parents. Two of these four were five-month-old males with both left-handed parents. In terms of the subject characteristics previously noted, these infants were in no ways different from the forty infants in the main group, with the one exception that all four infants showed a preference for a head-left posture. Two were first-born infants, and two were second-born. The mean durations of unimanual and bimanual grasp were comparable to those of the infants whose parents were right-handed. The hand differences, however, were in the opposite direction, with the left hand being favored. Overall, the hand asymmetry was somewhat less

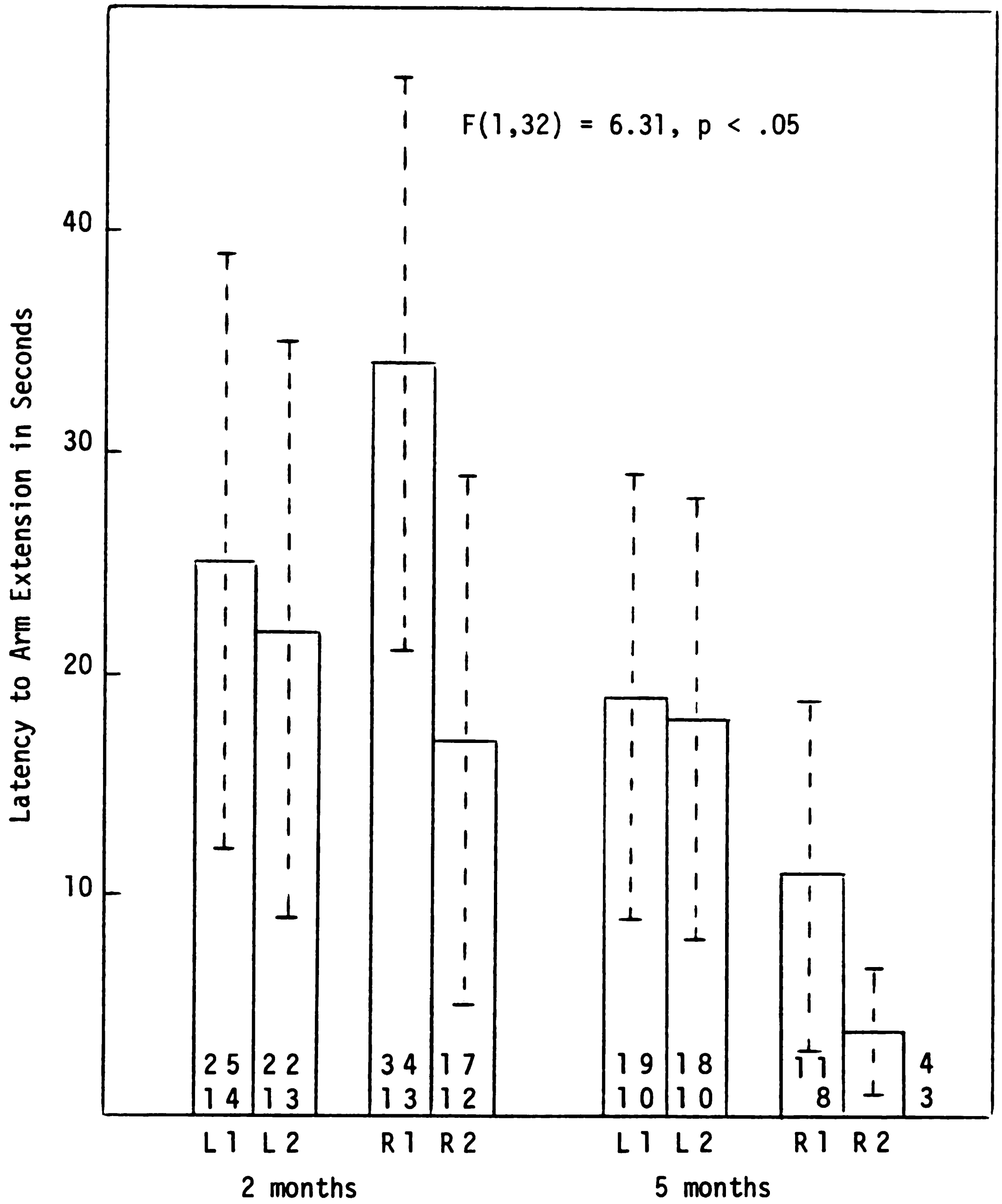


Figure 5. Latency to contralateral reaching in seconds for each hand, within each age group, over two trials.

pronounced in these two infants than in the forty "right-handed" infants. No preference was shown for one hand over the other in reaching. Similarly on the latency measure, average times were comparable to those of the other infants, but the asymmetry was toward the left and not as marked. The remaining two infants in the "left-handed" group were a two-month-old male and a five-month-old female, both of whom had a left-handed father. Once again, although the average times for grasp and latency were comparable to the respective experimental groups, no manual asymmetries were evident.

These findings, although based on too few subjects to be reliable, allow for some speculation. Evidence has been presented above that left-handed adults tend to be less well lateralized, in terms of both manual and cerebral specialization, than right-handed adults. None of the studies of cerebral asymmetries in infants have compared infants of right-handed parents with those of left-handed parents. Consequently, it is not known whether the less pronounced lateralization found in left-handed adults is present in their children. This possibility remains to be tested with larger numbers of infants with family histores of sinistrality.

Individual Differences

One individual difference that was highly correlated with overall performance, although not with asymmetry, was prandial condition. Those infants tested pre-prandially showed longer grasp durations and shorter latencies to reaching than did post-prandial infants.

Of all the subject characteristics obtained, the only one that yielded systematic individual differences in asymmetry was handedness history. No significant correlations were obtained with birth weight, gestation period, birth order, or any of the categories of behavior on the temperament scale. Only familial handedness history seemed to differentiate among the infants. This differentiation can be seen by an examination of Figure 6, a scatter plot comparing laterality indices obtained on the two grasp duration tasks. The correlation between the unimanual and bimanual laterality indices was $r = 0.57$ for the forty infants in the main group. All infants in this group showed positive laterality indices on both tasks (i.e., a right-hand advantage). The four infants with some history of left-handedness are represented by the four open circles. All four of these infants showed laterality indices with negative values or close to zero, indicating a weaker asymmetry in a direction opposite to that of the main group. These same infants also showed a left-side posture preference that stands in contrast to the right-side preference of the infants of right-handed parents.

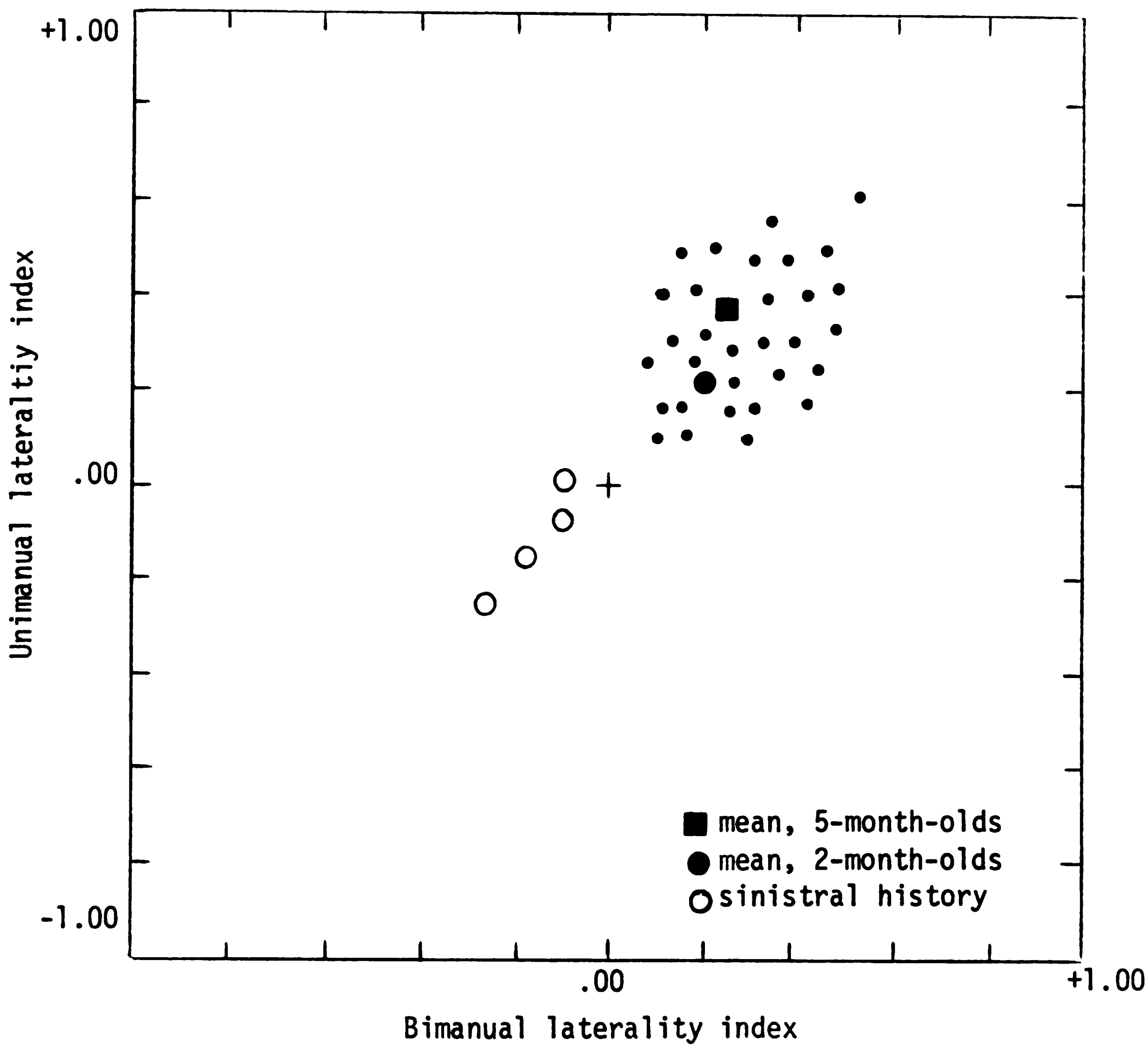


Figure 6. Scatter-plot of laterality indices for unimanual and bimanual grasp duration tasks.

DISCUSSION

Summary

To summarize, both measures of grasp duration as well as the latency to reaching were related to age and hand. With increasing age, duration of grasp increased and latency to reaching decreased. The same trends of longer grasp duration and shorter latency were significantly more marked for the right hand than for the left hand. On all three measures, age interacted with hand to influence the degree of the asymmetry. The hand difference was generally stronger in the older infants on all three tasks, although it was also present in the younger infants on one of the three (unimanual grasp). Absence of hand differences in the younger infants on the bimanual and reaching tasks may be the result of increased task difficulty.

The ability to grasp an object is a basic skill which must be acquired before any sort of object manipulation is possible. Grasp is a fundamental component on which other skill components are built. It is expected that any hand asymmetries apparent in an infant at a given age would appear in the earlier mastered, more fully developed skills. This idea receives some support by comparing across tasks the number of infants who showed positive laterality indices. On the unimanual grasp task, all infants in both age groups showed a right-hand advantage. On the bimanual grasp task, all five-month-olds showed a right-hand advantage, while the two-month-olds showed a much weaker asymmetry. On the reaching task, both age groups showed a weaker right-hand advantage. These findings indicate that if asymmetries in manual use are to be found in infants, they will be found in those skills on which the infant has mastery. Manual asymmetry in early infancy may be expressed as differential efficiency of the two hand rather than differential choice of or preference for one hand over the other. Increased efficiency of hand use in grasping and reaching is a major outcome of motor skill development.

Development of Motor Skills

A more extended description of motor skills is necessary so that the relationship of handedness and motor skill, and the measurement issues previously discussed, can be re-evaluated. The two skills of major importance for the present study are those of grasping and reaching.

Grasping, or prehension, is based on the reflex substrates that develop and change during the first few months after birth. Three types of automatic grasping response, the traction response, the grasp reflex, and the instinctive grasp reaction (Twitchell, 1965; 1970) have been described above. During the period when the traction response is dominant, no voluntary prehension occurs, though an object placed in the infant's hand may be held momentarily, particularly if tension is applied to the shoulder muscles. More effective prehension involved in visually directed reaching occurs after about four months of age and is preceded by the maturation of the grasp reflex. At this stage, the whole hand is involved in a palmar grasp. The precision grasp, marked by finger-thumb opposition, begins to emerge around eight months of age.

In a later paper, Twitchell (1970) discusses how the hand is projected into the visual field. Well-coordinated projections of the limb into space occur only following the development of the instinctive grasp reaction. Most studies of the development of prehension emphasize visual guidance, but Twitchell's work suggests that the appearance and integration of the grasping and avoiding responses are essential. During development, these grasping and avoiding reactions to a contact stimulus emerge in an orderly and overlapping fashion. In the early stages of visually directed reaching, an object is approached from above and grasped only when the palm of the hand comes into contact with it. Following the emergence of the orientation phase of the instinctive grasp reaction, and the acquisition of individual reflex responses to contact on individual digits, the hand adapts to the object. The radial (lateral) aspect of the hand is directed at the object, and dexterity is improved.

The work of Bower (1972, 1975) and co-workers (Bower, Broughton, & Moore, 1970a, 1970b) on reaching stems from a more general interest in object perception and object concept development. They provide evidence for the dominance of visual over tactual information in infant's reaching, including the absence of reaching attempts toward a virtual stimulus, more attempts to reach a near object than a far-away object, increased anticipatory finger-thumb separation with increased stimulus size, anticipatory hand positioning based on object characteristics, and crying in young infants following failure to contact a virtual object. Bower's theoretical framework seems to be that coordination of vision and prehension is present at birth and that differentiation during infancy involves improvements in perceptual discrimination and information processing, reflecting increased voluntary control.

Bruner's (1970; Bruner & Koslowski, 1972) work on the development of reaching can be summarized as follows. At one month, a peripherally moving stimulus will be pursued via head movement. If the object approaches the infant, a number of changes will be noted in general activity, including increased tension in the trunk, lifting the shoulders and flexing the arms at six weeks, fixed gaze and pumping motions of the upper extremities at ten to twelve weeks. Swiping movements of the fisted hand will be followed at four months by a slower reach with the hands wide open. Visual guidance involves fixating on the object, not looking back and forth from hand to object. Execution of reaching may even be accompanied by gaze aversion or eye closing (Bruner, 1968). The early coordination of grasping activity with visual information is suggested by the finding that infants at age eight weeks made more attempts to grasp an object of graspable size than an object too large to be grasped (Bruner & Koslowski, 1972).

Briefly, Bruner (1970) conceptualizes skilled activity as a program specifying a terminal state to be achieved, and requiring the serial ordering of a set of constituent, modular subroutines.

Functionally equivalent variations in serial order and substitution rules for constituent subroutines are features of skilled activity that allow it to be productive. Variations in serial order assure flexibility and productivity by making possible appropriate changes in the order in which constituent subroutines are used. The more a skill is linked in time with physical situational requirements, the fewer the functionally equivalent variations possible. A developed skill has "rules" that include appropriate variant orders, and exclude inappropriate ones. The constituents of skilled action appear to come from two sources. One is the innate repertoire of action patterns evoked by interaction with the environment. The second is the differentiation of initially gross acts into component elements which are available for inclusion in new behavior sequences.

Halverson's (1931, 1932, 1937) detailed studies of reaching responses and the prehensile grasp were founded on Gesell's maturational theory of development. His findings may be summarized as follows. At sixteen weeks, reaching, if present, is achieved by a very circuitous approach of the hand to the object. This remains noticeable until 36-40 weeks, when the trend to a more direct approach is pronounced. Between 16 and 24 weeks, hand movements described as incipient approaches were noted, taking such forms as a raising of the hand or movements of the fingers. The circuitous approach favored by the younger groups consisted of side to side movements of the forearm, with the degree of arm extension determining successful object contact. Until 36 weeks, there persisted a declining tendency to place the hand behind the object and draw it toward the body by arm flexion. By 36 weeks, the approach is much straighter, and by 52 weeks almost perfectly straight. The straightening of the route of the hand to the object is accomplished by the elimination of medial deviation prior to lateral deviation. Halverson suggests that this improves visual control over reaching since medial deviation obscures object vision.

In addition to deviations in the horizontal, there are deviations in the vertical which are also eliminated during the course of development. At 16 weeks, Halverson found substantial upward and downward hand travel at the start and finish of the movement. This vertical "loop" movement is replaced at 24 to 28 weeks by a sliding movement. From 36 to 52 weeks, a planing response was observed in which there was no deviation, the hand planing out toward the object in a long arc.

Findings on hand configuration indicate that prior to 28 weeks, the grasp does not appear to involve thumb opposition. The object is held in a power grip, a clamp of flexed fingers into the palm. The thumb flexes but not in opposition. Opposition appears around 28 weeks, and from about 36 weeks, finger-tip grasping is progressively the preferred method. There is also a trend for the object to move distally and radially with respect to the palm.

McGraw's (1941) study of reaching and prehensile behavior led to the proposal of six developmental stages. In the newborn or passive phase (first 35 days), an object in the visual field elicits no over response. The infant may momentarily maintain hold on an object that is placed in the hand. During the object-vision phase (115 days), the infant begins to fixate and respond to near objects. At the onset of this stage, object fixation is accompanied by a decrease in on-going muscular activity. After visual perception becomes more developed, the sign of an object may be accompanied by disorganized, diffuse activity. In the visual-motor phase (210 days), the approach of an object evokes bilateral approach movements of the arms and fingers. Improvement in the ability to grasp and retain the object occurs during this phase. During the manipulative-deliberate phase (360-375 days), the reaching action becomes more deliberate in quality, and sustained attention to the object appears. In the visual release phase (500+ days), sustained attention is no longer necessary to carry out reaching. The mature phase (1200+ days) is indicated when both the visual and neuro-muscular components have been reduced to the minimum required by the situation. McGraw suggests that the increased skill in reaching and prehension is an outcome of neural maturation.

Piaget (1936; Piaget & Inhelder, 1956) suggests that the coordination of vision and prehension in reaching is an example of the process of reciprocal assimilation. On the basis of his observations, he defines five stages in the development of reaching. The first stage is that of impulsive movements and of pure reflex. The newborn closes his hand involuntarily when the palm is lightly touched. The second stage is that of the first circular reactions related to hand movements, prior to any actual coordination between prehension and sucking or vision. During a third stage, there is coordination between prehension and sucking. In other words, the hand grasps objects which it carries to the mouth and reciprocally takes hold of objects which the mouth sucks. The fourth stage is that during which there is prehension as soon as the child simultaneously perceives his hand and the desired object. During the final stage, the child grasps that which he sees without limitations relating to the position of the hand.

This final coordination is conceived to be the result of reciprocal assimilation of the visual and manual schemata. As early as the second stage, the glance attempts to follow (i.e., assimilate) everything that the hand performs. During the third stage, the hand attempts to reproduce those movements which the eye sees (i.e., assimilate visual to manual). During the fourth stage this assimilation is extended to prehension when the hand appears in the same field of observation as the object to be grasped. The hand graps what the eye observes and vice versa. Finally, with complete reciprocal assimilation in stage five, all that is seen is also to be grasped, and grasped to be seen.

White, Castle, and Held (1964; White & Held, 1966) have also described the emergence of visually directed reaching. They give a ten-step analysis, culminating in visually directed reaching at around five months. At one to two months, a peripherally moving stimulus will produce head movements in pursuit. At two months, the infant will swipe with a closed fist in response to an object about 12 inches away. This swiping behavior, though accurate, is not accompanied by attempts at grasping. From three to four months of age, unilateral arm approaches decrease in favor of bilateral patterns. Unilateral responses reappear at about four months, but the hand is no longer fisted and is not usually brought directly to the object. Rather, the open hand is raised to the vicinty of the object and then brought closer to it as the infant shifts his glance from hand to object, until the object is grasped. Finally, just prior to five months of age, infants begin to reach for and successfully grasp an object in one quick, direct motion of the hand from outside the visual field.

Handedness and Motor Skill

The major developments in early motor skill, then, are the replacement of reflexive with voluntary responses and the increase in voluntary control and efficiency of the responses. The relationship of these developments to the development of hand asymmetries, in its most basic form, deals with the presence and the nature of early manual asymmetries. The results of the current study suggest that such asymmetries are present in early infancy. Given that asymmetries exist, how are they expressed? That is, do early asymmetries manifest themselves in preferential choice of one hand over the other for particular tasks, as in adults? The studies conducted by Baldwin and others on reaching showed that preferential choice did not become apparent until seven months of age. It is possible, however, that prior to this age, asymmetry may be expressed in a more fundamental manner, such as efficiency, skill, or effort expenditure in performing a task.

The results of the current and other related studies suggest that the asymmetry manifests itself in differential efficiency of the two hands. This is particularly obvious in the case of reaching. Shorter latencies from object presentation to completion of reach (i.e., full arm extension) suggest increased efficiency in performance of the components of reaching. As extraneous movements are eliminated, reaching becomes more efficient and requires less time. Similarly, since grasping is a precursor to and a prerequisite for successful reaching and object manipulation, it is reasonable to expect that asymmetry in grasp duration would predate preferential use of one hand. An initial asymmetry in efficiency of performance of motor activities may provide the basis for a later asymmetry in frequency of performance. That is, as the child becomes aware that one hand is more adept at certain skills, he may increase the frequency with which he chooses to use that hand.

Thus, one possible interpretation of the current findings is that manual asymmetries are found in early infancy, although in a form different from those found in older children and adults. These manual asymmetries would appear to be under genetic control, since different asymmetries are evident in infants with different familial handedness histories, and these differences appear very early in infancy. Reports of cerebral asymmetries in young infants are suggestive also of genetic influence on the early appearance of lateral asymmetries.

Alternative explanations of the findings of early hand asymmetries are possible. One of the most widely held alternatives is that of an attentional bias. Recent data have indicated that the infant is asymmetric in its posture and its response to auditory, tactile, and visual stimulation from a very young age (Turkewitz, 1977). It is possible that these asymmetries reflect a rightward bias of attention in infancy, although Turkewitz offers no explanation. Attentional asymmetries could account for the hand differences in grasp duration. That is, if an infant is differentially attending to stimulation of the right side, he may attempt to maintain stimulation on that side by holding on to the barbell longer than on the opposite side. However, an attentional hypothesis cannot account for the differential latencies in crossing body midline. Infants show shorter latencies when reaching with the right hand for an object to the left of midline, than when reaching with the left hand for an object to the right of midline. Assuming that the object, and not the hand, is the focus of attention, an attentional hypothesis would predict the opposite outcome. That is, if an attention bias toward the right side is operating, the predicted order of latencies, from shortest to longest, would be reaches to the right side with the right hand, reaches to the right side with the left hand, reaches to the left side with the left hand, and finally reaches to the left side with the right hand. The actual results, however, showed that ipsilateral reaches had shorter latencies overall than contralateral reaches and that contralateral reaches with the right hand had shorter latencies than contralateral reaches with the left hand. It does not appear that any attentional bias is operating.

The Concept of Handedness

In light of these and other findings of the presence of handedness in early infancy, it becomes necessary to "re-think" the concept of handedness and theories of its development. If a theory of a biological substrate for handedness is assumed, very few changes in handedness should be found across the life span since the cerebral asymmetries which form the biological substrate are present very early. Data that suggest increasing manual asymmetry with increasing age may be artifacts of choosing measurement tasks not within the infant's repertoire. In infancy, handedness may be expressed as differential efficiency of the hands rather than, or prior to differential preference.

To get a clearer idea of the nature of the biological bases for handedness, it will be necessary to examine infants of left-handed parents. The four subjects in this study with history of left-handedness show a pattern markedly different from that shown by infants of right-handed parents. The existence of several different types of left-handedness suggests that familial history is of critical importance in the study of handedness and that infants of parents with different types of left-handedness should be compared if the true basis of handedness is to be discovered.

Conclusions

The present results indicate that some forms of manual asymmetry appear as early as age two months. Two-month-old infants showed a right-hand advantage on a unimanual grasp task, and five-month-olds showed a similar advantage on both unimanaul and bimanual grasping tasks. Consistent with previous findings, neither age group showed any hand differences in frequency of reaching. The five-month-olds did, however, show a right-hand advantage on latency to reaching. That is, the right hand reached more rapidly than the left. In terms of individual differences, the only subject variable that was systematically predictive of performance was familial handedness history. Four infants with one or both left-handed parents were tested. Overall, these infants showed weaker asymmetries than the infants of right-handed parents, and asymmetries toward the left rather than toward the right.

APPENDICES

APPENDIX A

PARENTS' QUESTIONNAIRE

APPENDIX A

PARENTS' QUESTIONNAIRE

Subject Number ________________

Part 1 - Handedness History

Please indicate your hand preference for these activities using the following code. If you need to give any additional information to explain your answers, please do so in the spaces provided for comments. Make sure you indicate the number of the question that you are explaining in your comments.

1 = Always with your left hand
2 = Usually with your left hand
3 = No preference; either your right or left hand
4 = Usually with your right hand
5 = Always with your right hand

1. To write a letter legibly ____________
2. To draw a map or picture ____________
3. To throw a ball to hit a target ____________
4. To play a game requiring a racquet (e.g., tennis) ____________
5. To hold a match when striking it ____________
6. To use a bottle opener ____________
7. To hold scissors while cutting paper ____________
8. To deal playing cards ____________
9. To hammer a nail into wood ____________
10. To hold a toothbrush while cleaning teeth ____________

Comments:

Your age: _______

Your sex: Male _______ 1

Female_______ 2

The following questions are concerned <u>only</u> with your relatives who are biologically related to you, not those related only by marriage or adoption. Please indicate <u>their</u> hand preferences using the following code.

1 = Left handed
3 = No preference
5 = Right handed
0 = Don't know

1. Father ____________
2. Mother ____________
3. Sister ____________
4. Sister ____________
5. Sister ____________
6. Sister ____________
7. Brother ____________
8. Brother ____________
9. Brother ____________
10. Brother ____________

If you have additional siblings, please record their sex and hand preferences below.

Comments:

	Hand	Age
11. Daughter	____________	____________
12. Daughter	____________	____________
13. Daughter	____________	____________
14. Daughter	____________	____________
15. Son	____________	____________
16. Son	____________	____________
17. Son	____________	____________
18. Son	____________	____________

If you have additional children, please record their sex, age, and hand preference below.

Comments:

Part 2 - Pregnancy and Delivery Information

In the following questions, please fill in the blanks either with a check mark where required or the appropriate information.

1. Was this your first pregnancy and delivery?

   ____________ 1 No How many others? ____________

   ____________ 2 Yes

2. What was your baby's weight at birth?

   ____________ pounds ____________ ounces

3. What was the length of your pregnancy?

   ____________ weeks ____________ days

4. According to the due date your doctor gave you, was your baby born . . .

   ____________ 1 early (by ____________ days)

   ____________ 2 about on time

   ____________ 3 late (by ____________ days)

5. Approximately how long were you in labor?

   ____________ hours

6. How would you rate the difficulty of your labor on a scale from 1 (very easy) to 5 (very difficult)?

   ____

7. Was your baby's delivery. . .

   ____________ 1 essentially normal

   ____________ 2 complicated by an unusual presentation (e.g., breech)

   ____________ 3 by Caesarean section

8. Were you given any drugs or medication during labor or delivery?

   ____________ 1 No

   ____________ 2 Yes Please describe them briefly to the best of your knowledge.

9. Did any complications arise during delivery or during your baby's stay in the hospital?

   ____________ 1 No

   ____________ 2 Yes Please describe them briefly to the best of your knowledge

10. Has your baby suffered any serious illnesses or injuries since birth?

____________ 1 No

____________ 2 Yes Please describe them briefly to the best of your knowledge

Part 3 - Infant Behavior Profile

Following is a series of descriptions of various aspects of your baby's daily activities, including sleeping, eating, bathing, dressing, and playing. In the blank space before each question, please fill in the letter (a, b, or c) of the response which best fits your baby's typical behavior.

Sleep

____________ 1. A) Generally goes to sleep at about the same time for night and naps (within 1/2 hour).

B) Partly at the same times, partly not.

C) No regular pattern. Times very 1-2 hours or more.

____________ 2. A) Generally wakes up at about the same time from night and naps (within 1/2 hour).

B) Partly the same times, partly not.

C) No regular pattern. Times very 1-2 hours or more.

____________ 3. A) Generally happy (smiling, etc.) on waking up and going to sleep.

B) Variable mood at these times.

C) Generally fussy on waking up and going to sleep.

____________ 4. With a change in time, place or state of health:

A) Adjusts easily and sleeps fairly well within 1-2 days.

B) Variable pattern.

C) Bothered considerably. Takes at least 3 days to readjust sleeping routine.

Feeding

____________ 5. A) Generally takes milk at about the same time. Not over 1 hour variation.

B) Sometimes same, sometimes different times.

C) Hungry times unpredictable.

____________ 6. A) Generally takes about same amount of milk, not over 2 oz. difference.

B) Sometimes same, sometimes different amounts.

C) Amounts taken unpredictable.

____________ 7. A) Easily adjusts to parents' efforts to change feeding schedule within 1-2 tries.

B) Slowly (after several tries) or variable.

C) Adjusts not at all to such changes after several tries.

____________ 8. A) With interruptions of milk or solid feedings, as for burping, is generally happy, smiles.

B) Variable response.

C) Generally cries with these interruptions.

____________ 9. A) Always cries loudly when hungry.

B) Cries somewhat but only occasionally hard or for many minutes.

C) Usually just whimpers when hungry, but doesn't cry loudly.

____________10. A) After feeding, baby smiles and laughs.

B) Content but not usually happy or fussy.

C) Fussy and wants to be left alone.

____________11. A) When full, clamps mouth closed, spits out food or milk, bats at spoon, etc.

B) Variable.

C) Just turns head away or lets food drool out of mouth.

____________12. A) Initial reaction to new foods (solids, juices, vitamins) acceptance. Swallows them promptly without fussing.

B) Variable response.

C) Usually rjects new foods. Makes face, spits out, etc.

____________13. A) Initial reaction to new foods pleasant (smiles, etc.) whether accepts or not.

B) Variable or intermediate.

C) Response unpleasant (cries, etc.) whether accepts or not.

____________14. A) This response is dramatic whether accepting (smacks lips, laughter, squeals) or not (cries).

B) Variable.

C) This response is mild whether accepting or not. Just smiles, makes a face, or no expression.

____________15. A) After several feedings of any new food, accepts it.

B) Accepts some, not others.

C) Continues to reject most new foods after several tries.

____________16. A) With changes in amounts, kinds, timing of solids, does not seem to mind.

B) Variable response. Sometimes accepts, sometimes not.

C) Does not accept these changes readily.

Soiling and Wetting

____________17. A) When having bowel movement, generally cries.

B) Sometimes cries.

C) Rarely cries though face may become red. Generally happy (smiles, etc.) in spite of having bowel movement (b.m.).

____________18. A) Bowel movements generally at same time of day (usually within 1 hour of same time).

B) Sometimes at same time, sometimes not.

C) No pattern. Usually not same time.

____________19. A) Usually fusses when diaper soiled with b.m.

B) Sometimes fusses.

C) Usually does not fuss.

__________20. A) Usually fusses when diaper wet (no b.m.).

B) Sometimes fusses.

C) Usually does not fuss.

__________21. A) When fussing about diaper, does so loudly. A real cry.

B) Variable.

C) Usually just a little whimpering.

__________22. A) Generally pleasant (smiles, etc.) during diapering and dressing.

B) Variable.

C) Generally fussy during these times.

__________23. A) These feelings usually intense: vigorous laughing or crying.

B) Variable.

C) Mildly expressed usually. Little smiling or fussing.

Bathing

__________24. A) Usual reaction to bath: smiles or laughs.

B) Variable or neutral.

C) Usually cries or fusses.

__________25. A) Like or dislike of bath is intense. Excited.

B) Variable or intermediate.

C) Like or dislike is mild. Not excited.

__________26. A) Reaction to very first tub (or basin) bath. Seemed to accept it right away.

B) Neutral.

C) At first, protested against tub.

__________27. A) If protested at first, accepted it after 2 or 3 times.

B) Sometimes accepted, sometimes not.

C) Continued to object even after two weeks.

__________28. A) If bath by different person or in different place, readily accepts change first or second time.

B) May or may not accept.

C) Objects consistently to such changes.

Procedures--Nail cutting, hair brushing, washing face, etc.

__________29. A) Initial reaction to any new procedure is generally acceptance.

B) Variable.

C) Generally objects; fusses or cries.

__________30. A) If initial objection, accepts after 2 or 3 times.

B) Variable acceptance. Sometimes does, sometimes does not.

C) Continues to object even after several times.

__________31. A) Generally pleasant during procedures once established--smiles, etc.

B) Neutral or variable.

C) Generally fussy or crying during procedures.

Visits to Doctor

__________32. A) With physical exam, when well, generally friendly and smiles.

B) Both smiles and fusses; variable.

C) Fusses most of the time.

__________33. A) With shots cries loudly for several minutes or more.

B) Sometimes cries loudly, sometimes not.

C) Cries less than a minute.

__________34. A) With any kind of illness, much crying and fussing.

B) Variable.

C) Not much crying with illness, just whimpering sometimes.

__________35. A) Reaction to light or sound is intense. Baby startles or cries loudly.

B) Intermediate--somtimes does, sometimes not.

C) Mild reaction--little or no crying or startle.

__________36. A) On repeated exposure to these same lights or sounds, does not react so much any more.

B) Variable.

C) No change from initial negative reaction.

Responses to People

____________37. A) Initial reaction to approach by strangers positive, friendly (smiles, etc.).

B) Variable reaction.

C) Initial rejection or withdrawal.

____________38. A) This initial reaction to strangers is intense: crying or laughing.

B) Variable.

C) Mild-frown or smile.

____________39. A) General reaction to familiar people is friendly--smiles, laughs.

B) Variable reaction.

C) Generally glum or unfriendly. Little smiling.

____________40. A) This reaction to familiar people is intense--crying or laughing.

B) Variable.

C) Mild--frown or smile.

Reaction to New Places and Situations

____________41. A) Initial reaction acceptance--tolerates or enjoys them within a few minutes.

B) Variable.

C) Initial reaction rejection--does not tolerate or enjoy them within a few minutes.

____________42. A) After continued exposure (several minutes) accepts these changes easily.

B) Variable.

C) Even after continued exposure, accepts changes poorly.

Play

____________43. A) Takes new toy right away and plays with it.

B) Variable.

C) Rejects new toy when first presented.

____________44. A) If rejects at first, after short while (several minutes) accepts new toy.

B) Variable.

C) Adjusts slowly to new toy.

____________45. A) Play usually accompanied by laughing, smiling, etc.

B) Variable or intermediate.

C) Generally fussy during play.

____________46. A) Play is intense: much activity, vocalization or laughing.

B) Variable or intermediate.

C) Plays quietly and calmly.

APPENDIX B

DESCRIPTION SHEET

APPENDIX B

DESCRIPTION SHEET

Head Posture Preference

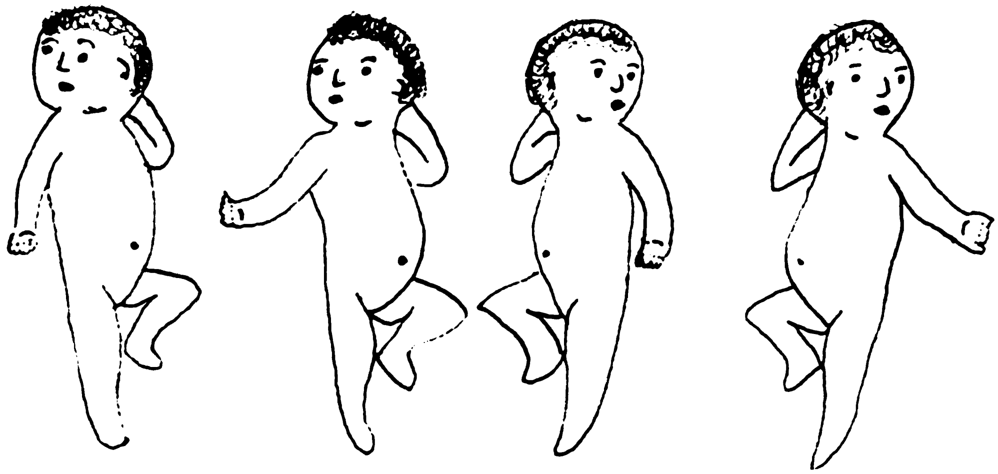
You most likely have noticed that your baby has very definite preferences for some things. One of the most noticeable preferences is that babies like certain postures or positions more than others. When a baby lies on its back it usually turns its head to the left or the right instead of looking straight ahead. Certain arm and leg movements accompany this head position. One combination of head, arm, and leg positions that babies show is called a tonic neck reflex, or TNR position. The pictures on page three illustrate this position. It occurs only when the baby is lying on its back. The baby's head is turned far to one side--in drawing 1A and 1B to its own right, in 2A and 2B to its own left. The arm on the same side is extended, either down parallel to the body (1A and 2A) or out to the side at a right angle to the body (1B and 2B). The baby's other arm is bent so that the hand is close to the shoulder or the back of the head. The leg on the same (face) side is extended straight down while the other leg is bent at the knee. The baby's position strongly resembles that of a sword fighter who is fencing. All four of these positions are normal for all infants, but some may be more frequent than others.

I would like you to watch for this position in your infant. The drawings may be of some help to you in your observations. Specifically, I want to know whether your baby prefers to turn its head toward the left or toward the right (the baby's <u>own</u> left or right, not your left or right). While you are going through your daily routine, when you see your baby lying in this position, just note whether the head is turned left or right and which arm and leg is bent or extended. Make a mark under the drawing on page 3 that best matches your baby's position. This way, you can keep track of the frequency of each position and determine your baby's preference.

Since babies are almost always moving, it may be difficult for you to notice this position at first. If you keep watching, your baby will take this position, even if the arms and legs are in motion. There is just one thing you will have to watch out for. If your baby always lies in bed with its head turned toward the right, for example, it may be because this position allows him to see out the window or to look at interesting activity in the room. Or, if your baby lies in the playpen or on the floor with the head always turned left, it may be because the television or your favorite chair (with you in it!) is to the left. In other words, while you are observing, try to find situations where nothing influences the direction of your baby's head turns and arm and leg movements. With this description and pictures, I'm sure your observations will be quite accurate.

For each of your observations, just make a mark under the drawing on the next page that best matches your baby's position.

Also, please make a note of what the baby was doing when this position was observed--for example, sleeping, lying in playpen, dressing, etc. Try to make at least three observations each day if possible.



1A 1B 2A 2B

Right TNR Left TNR

APPENDIX C

RATING SCALE FOR STATE

APPENDIX C

RATING SCALE FOR STATE

State name	Description
Quite sleep	-Body appears generally relaxed. -Relaxation is interrupted by brief, periodic, spontaneous startles. -Eyes are usually closed. -Respiration is slow and regular.
Active sleep	-Diffuse movements occur frequently. -Movements may involve whole body but typically involve extremities and face. -Eyes are usually closed but conjugate eye movements may be noted. -Respiration is more irregular and rapid than in quiet sleep.
Drowsiness	-Body relaxation increases as infant falls asleep, then decreases sharply as infant jerks awake. -Eyelids may flutter and eyes, when open, have a glassy appearance. -Respiration more apt to be regular than irregular.
Quiet awake	-Little gross motor activity is apparent, although there may be movements of the extremities and face. -Eyes are open and characterized by a bright, shiny appearance. -Vocalizations are generally of a happy variety. -Respiration is relatively regular.
Active awake	-Considerable gross motor activity is present. -Vocalizations are of the cranky, fussy variety. -Respiration is often quite irregular.

Crying awake	-Criteria are the same as above except that, in addition, the infant is crying. -Tears may or may not be present. -The lower limit of crying is defined as a definite, sustained protest.

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